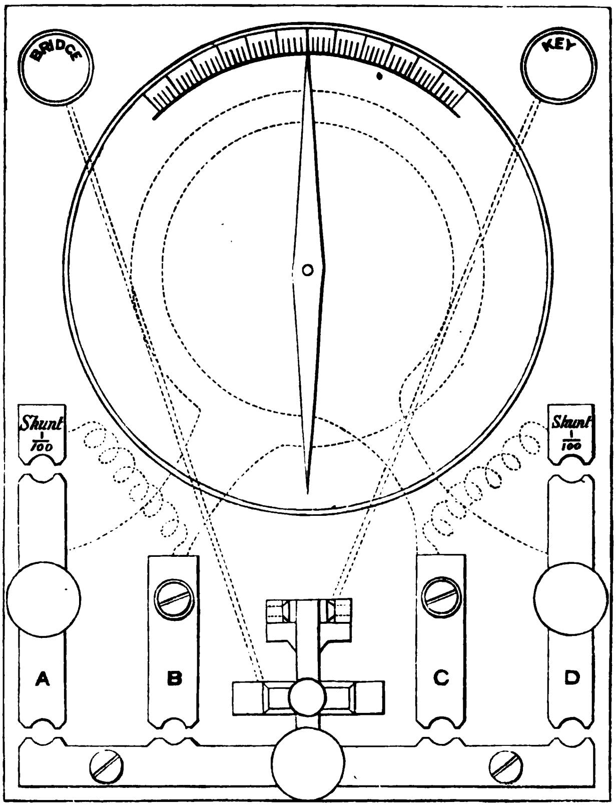

DIAGRAM OF CONNECTIONS. *Frontispiece.*

AN

ELEMENTARY TREATISE

ON

ELECTRICAL MEASUREMENT.

FOR THE USE OF TELEGRAPH INSPECTORS AND OPERATORS.

BY LATIMER CLARK.

LONDON:

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PREFACE.

THE Author having had occasion to write a little Manual to accompany some instruments designed for a special purpose, has thought that its publication might be of use to students preparing themselves for the service of the Electric Telegraph, and to others who might desire an Elementary Treatise on the subject of Electrical Measurement. The first half of the work is designed for the use of the student, and the practical telegraphist who has not given much time to the study of his subject, and is therefore written in a somewhat colloquial style: it is possible that from this cause it may prove more readable and attractive than works of a more advanced character, and may tend to awaken an interest in the subject among many who have hitherto been content to employ the services of electricity daily without caring to acquaint themselves with the laws of its operation.

The Author believes that the form of galvanometer herein recommended will be found a very useful and convenient instrument for all the practical measurements of telegraphy. Unlike ordinary galvanometers,

it is peculiarly suited for testing batteries, and the measure of their internal resistance is perhaps more easily and expeditiously obtained by this instrument than by any other method.*

The latter half of the work is in the form of an Appendix, which has been added to the original treatise in order to make it useful to the practical electrician. It contains a variety of formulæ, tables, and data for general use, chiefly taken from the author's note-book; and also a description of the methods of measurement usually employed in telegraphy, with the formulæ relating to them, which may often serve as an aid to the memory. The algebraic expressions throughout the book are put into a form especially intended for the use of those who do not often have recourse to them. The book having thus been written in two different portions, is necessarily wanting in all unity of design, for which, as for other imperfections, the author claims the indulgence of his readers. His acknowledgments are due to Mr. J. C. Laws for the assistance he has rendered in revising most of the calculations in the work.

5 *Westminster Chambers,*
London, 1868.

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* This instrument is made by Messrs. Warden and Co., of Church Street, Westminster.

CONTENTS.

ON

ELECTRICAL MEASUREMENT.

THE student of electricity in considering the various phenomena which come under his notice must of necessity form some theory in his mind as to the nature of the element with which he has to deal; and as philosophers are not in accord as to its nature and the theory of its action, the choice must to a novice be a difficult one. Without therefore in the least offering any opinion upon this point, I would advise him, until his views are more matured, to regard electricity as a *substance* like water or gas, having a veritable existence, and although easily convertible into heat, and *vice versâ*, in other respects indestructible.* I would advise him to dismiss from his mind all ideas about the existence of two different kinds of electricity, and to regard the earth as a vast reservoir highly charged with one kind of electricity (positive), and to regard a telegraph or a battery as an arrangement by which electricity is pumped out of the earth at one point

* See note *a*, page 168.

and poured into it at another. When any object has less electricity than the neighbouring earth it is charged *negatively*, when it has more it is charged *positively*, and in either case electricity will endeavour to flow from the earth to it, or from it to the earth, until equilibrium is established.

The laws which govern the propagation of the electric current along conductors are so simple, and yet withal so important, that every telegraphist ought to be familiar with them. The most important of them was first enunciated by Ohm in 1827, and is known as Ohm's law. For a long time this remained entirely unappreciated; but its importance is now abundantly recognised, and Ohm's law forms the foundation of all electrical measurement. To understand its application it is necessary to have a clear conception of the meaning of the terms *electromotive force*, *resistance*, *tension*, and *quantity*, and these will be unfolded in the following chapters.

AN ELEMENTARY TREATISE

ON

ELECTRICAL MEASUREMENT.

CHAPTER I.

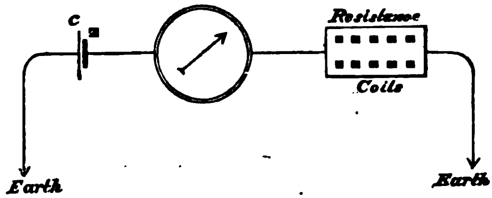
On Electrical Resistance.

TAKE the galvanometer described at page 45, and having inclined it on its back support, join it up in the manner described at page 51; that is to say, plug up the holes B and C, and also the $\frac{1}{100}$th shunts at A and B. Take one cell of a battery, and putting one pole to earth,* connect the other pole to the terminal A; then connect

* It is not essential to make any connection to earth, but the battery may be joined directly to the resistance coil (see Chapter VI.); nor is it necessary to employ this particular instrument; any galvanometer with very short and thick wire will suffice for this experiment: these are commonly called "quantity galvanometers," because they are capable of measuring larger quantities of current electricity than ordinary fine wire galvanometers.

the resistance coil to the terminal D, its other end being to earth; the arrangement will then be as follows:

Fig. 1.



Now short circuit the resistance coil by inserting all the plugs, and observe the deflection on the galvanometer; it will be found to be very great, probably 50° or more, depending on the resistance of the battery cell. Now gradually withdraw the plugs from the resistance coil, so as to interpose greater and greater resistance into the circuit; as this is done the needle will fall gradually back as the resistance is introduced, and its deflection will at last become scarcely visible. The construction of the galvanometer is such that its deflections are not truly proportioned to the force of the current; but when this is measured by suitable instruments the law is found to be simply this—that *the electromotive force being constant, the quantity of electricity which flows through any circuit is inversely proportional to the resistance;* that is to say, the greater the resistance, the smaller the current. Call-

ing the quantity Q, the electromotive force E, and the resistance R, this is expressed by the formula

$$Q = \frac{E}{R},$$

which is known as Ohm's law.

Hence if in any circuit with a given resistance, one farad of electricity* passes per second, then with twice that resistance we shall get a current of only half a farad per second; and with twenty, or one hundred and twenty times that resistance, we should get $\frac{1}{20}$th or $\frac{1}{120}$th of a farad per second. Again, with one-tenth of the resistance we shall get ten farads per second; it being understood that the electromotive force remains unchanged.

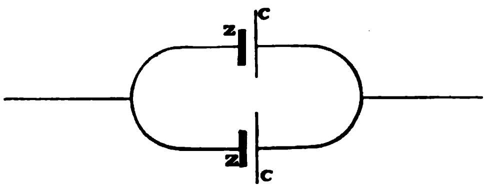
It is important to observe, that in speaking of the resistance in any circuit, we speak of the whole resistance, including that of the galvanometer, of the connecting wires or line circuit, and of the battery itself, which last is frequently a very important part of the whole resistance, and must on no account be forgotten.

This resistance may in practice originate in a variety of ways; a small cell gives much more resistance than a large one; and if the plates be far apart, the resistance is greater than when near together. If two similar batteries be joined up together in parallel circuit, or "for quantity" as it is sometimes termed, as shown in fig. 2, the resistance is only one half what one of them would give singly; and ten cells so joined up only give $\frac{1}{10}$th the

* The farad is a certain definite measure or quantity of electricity, see page 43. 44

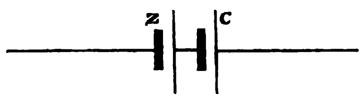
resistance of one of them: they are, in fact, in every way equivalent to one very large cell. On the other hand,

Fig. 2.



two or ten cells joined up in series as in fig. 3, give twice or ten times the resistance of one cell.

Fig. 3.



A partially dried or otherwise defective battery cell will often cause great resistance in a circuit, so will imperfectly soldered joints in a line wire; the soil itself, especially if dry and sandy, or rocky, will often oppose great resistance to the current: this is technically called "bad earth" (see page 40). Pure water offers a very high resistance, but if it contains any acids or saline matters in solution the resistance is much smaller: hence it is that clean rain in the country does not greatly injure the working of a line, but in towns, where the atmosphere is less pure, the insulation often becomes very imperfect in wet weather. It is from a similar cause that batteries

when first set up give a very weak current, and thus create the supposition that the electromotive force is feeble. This, however, is not so, as the addition of a little salt or acid will at once show: the real cause is the great resistance interposed in the circuit by the pure water before it has yet had time to become saturated with salts.

If an insulated line of telegraph ninety miles in length gives a resistance of, say 10,000 units, the *resistance per mile* will be ninety times 10,000, or 900,000 units; that is to say, each mile of the line conveys a certain quantity of electricity to the earth by reason of its imperfect insulation, and therefore the greater the number of miles the *smaller* is the total resistance; the average resistance of a single mile is therefore obtained by *multiplying* the total resistance by the number of miles.

The case is just the reverse when the line is connected to the earth at the distant end: the leakage or escape, which was before the only measure we dealt with, becomes in this case unimportant, and we measure the resistance of the metallic wire, instead of the resistance of the insulators. The greater the length of the wire the *greater* the resistance; and to obtain the average resistance of a single mile we have now to *divide* the total resistance by the number of miles. Thus if a ninety-mile line of No. 8 wire gave a resistance of 1215 units, the resistance of each mile would be $\frac{1215}{90}$ or 13·5 units.

CHAPTER II.

On Electromotive Force.

WE now pass on to the second part of the question, that of the *electromotive force.* Let us again take the galvanometer, joined up as before with one cell (fig. 1), and withdrawing all the plugs of the coil insert the whole of the resistance into the circuit, viz., ten thousand ohms. The deflection, as we noticed in the last experiment, will be extremely small. Now add a second cell to the battery and it will be found that the deflection is doubled; increase the cells to three and it will be trebled, and so on. The galvanometer, as before remarked, will not continue to give truly proportional deflections after the needle leaves its central position, but when proper means of measurement are employed, it is found that with a constant resistance *the quantity of electricity which flows through any circuit is directly proportional to the electromotive force.*

This is expressed by the formula above given, viz. :—

$$Q = \frac{E}{R}.$$

If then with any given resistance one cell gives a

current of ten farads per second, two cells will give twenty farads, and ten cells one hundred farads. It is scarcely necessary to say that in this case, as in the last, the resistance of the cells themselves must not be forgotten.

As an instance of calculation we will suppose now that with ten cells and a total resistance of ten units we get a current of one farad per second, and we desire to know from this what current would pass through a circuit of six units with one hundred and forty-four cells—we may reason thus :

If ten cells give one farad, then one hundred and forty-four cells will give 14·4 farads, or,

$$10 : 144 :: 1 : 14{\cdot}4.$$

And again, if with ten units' resistance we get 14·4, with six units we shall get more than this, viz. :—

$$14{\cdot}4 \times \frac{10}{6} = 24, \text{ or,}$$

$$6 : 10 :: 14{\cdot}4 : 24$$

The electromotive force does not in the least degree depend on the size of the cell, but is as great with a very minute pair of elements as with an immensely large pair; and if the one be opposed to the other, not the slightest current will pass.

We will now make another experiment, and it is one which the student should on no account neglect to perform for himself, as a great deal is to be learned from it.

Take the galvanometer still connected up as before

(fig. 1), and plug up all the resistance coil, so that there is no resistance in circuit except that of the galvanometer and the battery; or the resistance coil may be removed altogether. Note the deflection with one cell, and then add a second cell to the circuit; the result will perhaps be unexpected, for the deflection will be but very slightly increased. Add a third and fourth cells, and still there will be little or no increase in the deflection of the needle, and the same will be the case if we add one hundred cells, or five hundred cells! But how is this? We have just been taught that the quantity of current passing varies directly as the electromotive force (and we actually saw proof of it in the last experiment), and yet now we suddenly find that increasing the electromotive force one hundred or five hundred times has had scarcely any effect whatever. But let us look a little closer into the matter, and the anomaly will vanish.

Let us apply the two laws we have just learned to the case, and see whether the phenomena are, or are not, in accordance with the formula $Q = \frac{E}{R}$.

Let us suppose the resistance of each cell of the battery to be thirty units, and the resistance of the shunted galvanometer four units; we have then in the first case—

$$\frac{E}{R} = \frac{1}{30+4} = \frac{1}{34}$$

and in the second case, with two cells, we have—

$$\frac{2\,E}{2\,R} = \frac{2}{60+4} = \frac{1}{32}\ ;$$

and in the case of five hundred cells we have—

$$\frac{500\ E}{500\ R} = \frac{500}{15000+4} = \frac{1}{30 \cdot 008}$$

Although then we have doubled the electromotive force we have only increased the quantity of electricity flowing in the circuit from $\frac{1}{34}$ to $\frac{1}{32}$, and even when we increase the electromotive force five hundred times we only increase the current to $\frac{1}{30}$; the fact being that each battery brought as much resistance to the circuit as it brought electromotive force.

To make this still clearer, let us suppose the galvanometer taken away altogether and the batteries alone left in circuit: our calculation would then be in one case $\frac{E}{R} = \frac{1}{30}$, and in the other case—

$$\frac{500\ E}{500\ R} = \frac{500}{15000} = \frac{1}{30};$$

or, in other words, we get exactly the same current in one case as in the other. There arises from this the curious result, that if one or any number of similar cells be joined up on short circuit, without external resistance there will in every case be the same quantity of current flowing through them.

CHAPTER III.

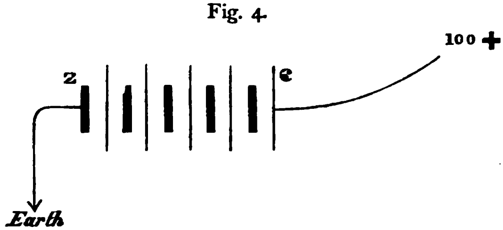
On Electrical Tension or Potential.

HAVING spoken of resistance and electromotive force, we will now treat of electric *tension* or *potential.* The two terms are perfectly synonymous, but the word potential is generally preferred by mathematical writers. There is often much confusion in the way in which the terms electromotive force and tension are indiscriminately employed, and it is well to endeavour to gain a clear idea of the distinction between them. We shall see as we go on that in a battery the electromotive force is the origin of the tension, and that the sum of all the electromotive forces is always equal to the sum of all the tensions, but their distribution is in every way different. To make the meaning of the term intelligible, we will cite a few cases of the effect of extreme tension, or potential, and then descend to more ordinary cases. Lightning is the most extreme case of tension with which we are acquainted (if we except perhaps the aurora borealis), and we may often see a flash a quarter of a mile in length. With an electrifying machine we may easily

obtain a tension high enough to make sparks leap across a space of six inches or a foot; descending to lower tensions, a Daniell's battery of five hundred cells will, when the circuit has once been established, maintain an arc of flame across a space of a quarter or half an inch; with still lower tensions, the electricity will traverse conducting substances freely, but will not pass across the air.

Degrees of tension are only relative, and we have no means of ascertaining the zero point of tension. The tension of the earth is called zero; but this tension varies slightly at different times and places, and we have no means of judging of its tension relatively to that of other planets and celestial bodies: just as a person enclosed within an electrified chamber has no means of ascertaining to what tension he is electrified, or whether his electricity is positive or negative; but taking the tension of the earth for the time being as a standard, we have no difficulty in comparing other tensions with it, with the most minute precision.

Fig. 4.

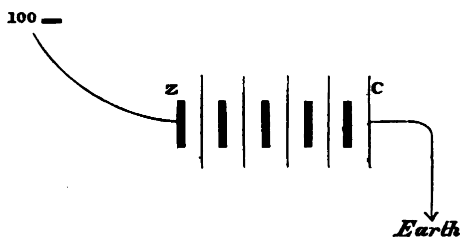


Take a battery of, say one hundred cells, and placing

it on a well-insulated stand, connect one pole of it, say the zinc or negative pole, to earth, and leave the other pole free, as in fig. 4: the end which is connected to the earth will now have a tension of 0, and the opposite end will have a tension of 100 positive, or *above* that of the earth; and if a wire were connected from it to the earth, a powerful current would flow from it to the earth.

Now reverse the connection, and place the other pole to earth, as in fig. 5. The copper end of the battery

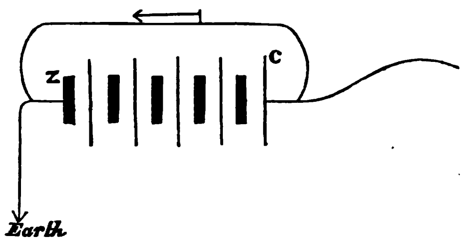
Fig. 5.



will now have a tension of 0, and the zinc or negative end will have a tension of 100 minus, or *below* that of the earth; and if a wire were connected from it to the earth, a powerful current would flow from the earth to it. In each of these cases the degree of tension is the same, but in one case it is higher than that of the earth, and in the other lower; the one is positive, the other negative.

Now take the same battery and connect it up, as in the first instance, with the zinc or negative pole to earth; but instead of leaving the positive pole free, join a short and thick wire across from the one pole to the other, as in fig. 6. An important change now occurs. We know

Fig. 6.



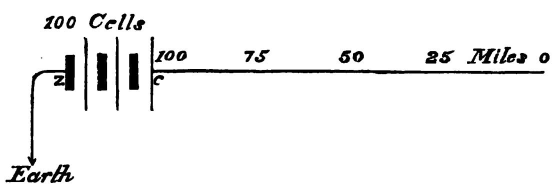
from previous experiments that a powerful current will circulate through the wire from *c* to *z*, and knowing the resistances we have the means of calculating the strength of this current; we know also that the electromotive force is not in any way affected by thus putting the battery into action. But although the *electromotive force* has not changed, we shall find on examination that the exterior *tension* has almost entirely disappeared: the wire at *c*, which in fig. 4 was at a tension 100 degrees above that of the earth, has now a tension but little above that of the earth.

If we now change the short and thick wire which

connects the poles *c* and *z* for a wire offering greater resistance, we shall soon find the tension at *c* begin to rise, although the tension of *z* is constantly kept at o by its connection with the earth at that point: as we increase the resistance of this connecting wire so does the tension at *c* rise, until at last, when we have made the resistance infinitely great, as in fig. 4, we find it again 100: the tension is now equal to the electromotive force, but it can never under any circumstances exceed it.

Let us now imagine a battery of, say one hundred cells, connected to a perfectly insulated line of, suppose one hundred miles in length, as shown in fig. 7, not con-

Fig. 7.

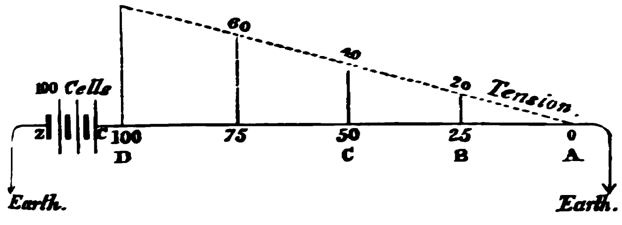


nected to earth at the distant end. The line will instantly obtain a tension of one hundred throughout its whole length (this being equal to the electromotive force of the battery), and it would do so equally if it were a thousand, or a million times that length: after this no current will flow from the battery.

Let us now imagine the distant end of the line connected to the earth; the battery will now come into

action, and a current will flow through the line. This will not in any way affect the electromotive force of the battery, but it will entirely change the tensions everywhere. The end connected to earth will of course at once assume a tension of o, and from this point all along the line up to the battery the tension will rise regularly and gradually; at the battery itself it will be something less than one hundred; but without at present stopping to calculate what, we will assume it to be eighty. Having ascertained the tension at this or any other spot, we can easily calculate it for every other part of the line, for in a circuit of uniform resistance *the tension varies directly as the distance from the zero end of the line.* Thus if it is equal to eighty cells at one hundred miles, it will be equal to forty cells at fifty miles, to twenty cells at twenty-five miles, to sixty cells at seventy-five miles, and so on. The tension will, in fact,

Fig. 8.



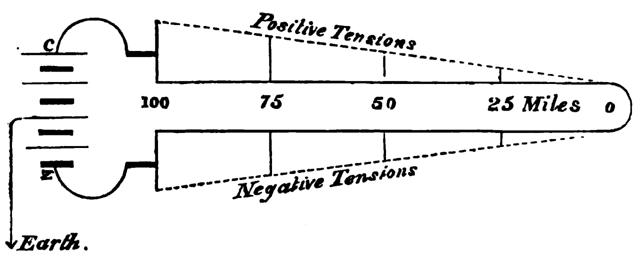
be represented at every point by the diagonal line in fig. 8; and knowing the tension at any spot in the line,

as D, we can obtain the tension at any other point, B or C, by simple proportion, viz. :—

Length A D : A B :: tension D : tension B.
or, 100 : 25 :: 80 : 20.

The tension thus spoken of has been *positive* tension, but the law is just the same with *negative* tension, or a tension less than that of the earth. We will take a case in which both tensions come into play. We have here

Fig. 9.



two parallel wires one hundred miles in length joined together at the distant end. The earth is connected now for the sake of illustration only at the centre of the battery, which has therefore a tension of 0, and may be considered as divided into two halves, the upper half giving a *positive* tension to the upper line, and the lower half giving a *negative* tension to the lower line. In the one case the tension falls, as before, regularly from the battery to 0, and in the other half it *rises* as regularly from the battery to 0. If a wire were connected from

the earth to the upper line at any part, a current of electricity would flow *from the line to the earth*, with an energy proportionate to the degree of tension. On the other hand, if the same wire were connected to the lower or negative line, a current would flow *from the earth to the line* with the same energy; and here it may be stated generally that *the quantity of electricity flowing along any conducting wire between any given points is directly proportional to the difference of tension between those points.* It does not in the least depend on the actual tension, which may be positive or negative, high or low, but purely on the *difference of tension* at the two points.

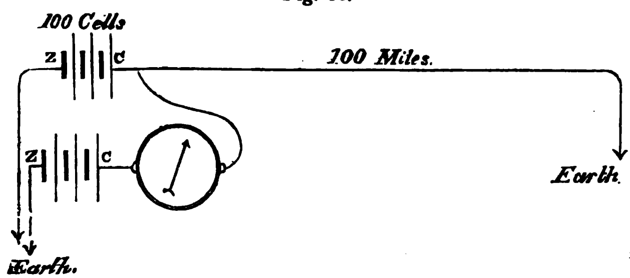
In the illustration above given there are two zero points, one in the centre of the battery which is connected to earth, and one in the centre point of the two lines: this arises from our having a negative current on one half the line, and a positive on the other. In practice it is usual to have either all positive tensions or all negative tensions, or else to alternate them one after the other.

We will now see how to measure these tensions; there are several methods, but perhaps the most useful for linework is the following:

Fig. 10 shows a line with a battery of one hundred cells connected to it, the distant end being to earth The galvanometer is connected to it at any point together with a second battery, its pole being also to earth; each battery is now trying to send a current into the line, and if both be attached at the same point, and

both of equal tension, both will send a current into the line, and the galvanometer will be deflected, say to the right. Now gradually reduce the number of cells in the secondary battery, and a point will soon be found at which no current will pass through the galvanometer either one way or the other, and the needle will be at zero. *The number of cells now in circuit in the secondary battery will represent the actual tension of the line at that spot.* If we take away another cell, the principal battery

Fig. 10.

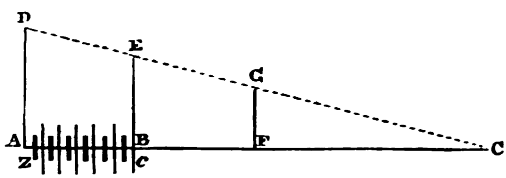


will send a current back through the secondary one, and the needle will deflect to the left; and if we add another cell, the smaller battery will begin to send a current into the line, and it will deflect to the right. When the tensions are equal, it will remain at zero. The number of cells in the secondary battery will always be smaller than in the principal battery, even when attached close to it, and as we get farther away from the station, the number of cells will diminish gradually, till near the

distant end where the line makes earth, even one cell will send a current into the line; in fact, the tension there becomes o. This experiment may be easily performed in a room, using a resistance coil to represent the line, and three or four cells for the principal battery, and it is a most instructive one.

We have seen at p. 15 how to derive the value of the tension at any one point from that at any other, we will now see how to calculate it from the electromotive force of the battery. Perhaps a diagram will make this clearer than any other method of explanation. Let A B (fig. 11)

Fig. 11.



represent a battery of, say one hundred cells, and let B C be a line of any length. Let the length of the line A B be drawn so as to represent the internal resistance of the battery (see page 60), and let the length of B C represent the resistance of the line. Let the height of the line A D represent the electromotive force of the battery, which we may call one hundred; then the height of the line B E will represent the tension of the line at its junction with the battery, and the height of the line F G will represent the tension at any other point, as F. The following rule will

therefore enable us to determine the tension at any point of the line, as, for example, F. *As the whole resistance of the line and battery is to the resistance measured from the distant end of the line* (C F), *so is the electromotive force of the battery to the tension at the spot* F ; or,

A C : F C :: A D : F G.

As an example, let a line four hundred miles long have a resistance of three units per mile, and let it be connected to a battery of fifty cells, each having a resistance of twenty units, and let us ascertain the tension at the middle of the line, or two hundred miles from its connection to earth. The total resistance in circuit will be $400 \times 3 + 50 \times 20, = 2200$ units; and the resistance measured to the centre of the line will be $200 \times 3 = 600$ units. The tension at that point will therefore be

2200 : 600 :: 50 cells : 13·64 cells ;

and the tension close to the battery will be

2200 : 1200 :: 50 : 27·27 cells;

being, of course, according to the rule at p. 15, equal to twice the tension at the centre of the line. It is evident that if the resistance of the line be exactly equal to that of the battery, the tension at the point where they join will be half the electromotive force; and the resistance of a battery may be ascertained in that way, viz., by varying the external resistance until the tension at the point of junction is half that of the battery when insulated : when this is the case the two resistances will be equal.

The following diagram will give some idea of the distribution of the tensions within the battery itself, where,

as far as regards the internal resistance, they follow the same law as elsewhere.

Fig. 12.

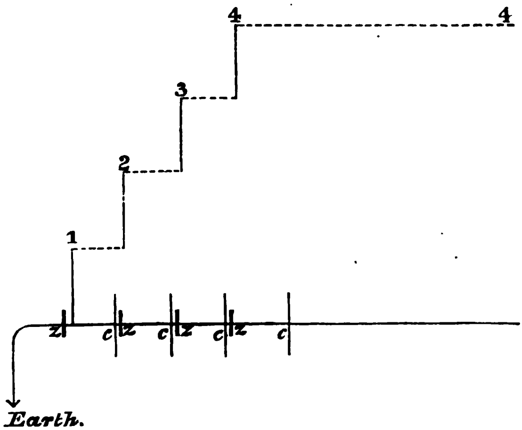
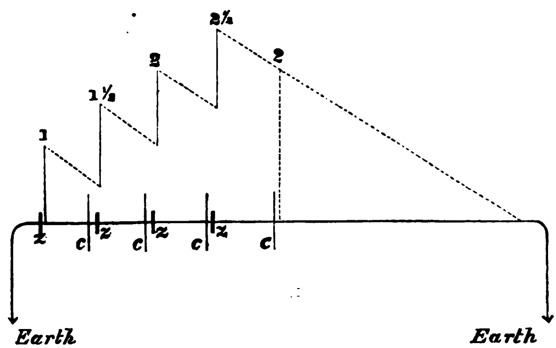


Fig. 12 shows a battery of four cells attached to a line of infinite resistance, that is to say, having its distant end insulated. The tensions are indicated by the upper line, and are in this case equal to the electromotive force. At each junction of the zinc with the liquid the latter rises in tension one cell, the whole tension attained being four cells.

Fig. 13 shows the same battery connected up to a line having exactly the same resistance as itself; the tension at the distant end, instead of being four, is zero; the tensions at the other points are figured on the diagram,

and according to the law before given, since the resistance of the line is equal to that of the battery, the tension at the junction will be half the electromotive force. It

Fig. 13.



will be seen that the tension falls in the liquid contained in the cells of the battery in proportion to the resistance, just as it does on the line.

Fig. 14 shows the same battery short-circuited, that is to say, connected to a thick wire connected to the earth, and which is supposed to offer an infinitely small resistance, and therefore to maintain both ends of the battery almost rigidly at zero. Here we see that the tension rises within the cells themselves as in the previous examples, the maximum point of tension being in the liquid which is in immediate contact with the zinc plate; it falls, however, to o at each copper plate, and this is the

case however many cells there be in the circuit. Within the cells the tensions fall in proportion to the resistances.

Fig. 14.

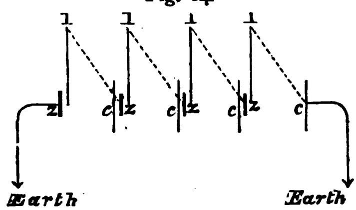
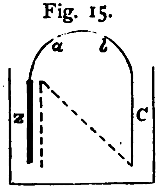


Fig. 15 shows a single cell of copper and zinc short-circuited by a wire *a b*, supposed to be so thick and so directly connected to earth as to maintain both plates almost rigidly to the tension of o: in this case the tension exists only within the liquid, as shown by the diagonal line. The tensions of the opposite ends of *a* and *b*, and consequently of *z* and *c*, are here assumed to be so nearly the same that they may be neglected. In all these cases we find the current conforming rigidly to the law $Q = \frac{E}{R}$, and we find also, as first stated, that *the sum of all the electromotive forces is equal to the sum of all the differences of potential.*

Fig. 15.

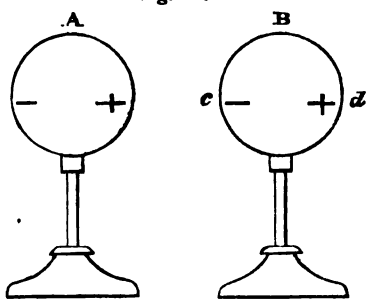


It may be remarked that tensions always tend to equalise themselves; all electrical currents are produced solely by differences of tension, and whenever the tension is greater at one spot than another, a current will commence

to flow from one to the other, and will continue until the tensions have become equalised; the quantity or strength of the current being greater or less according to the difference in the degree of tension, and the amount of resistance: however great or small these be, the tensions, if left undisturbed, will at length equalise themselves.

The tension too is the same *in the interior* of any conductor, whatever its form may be, as it is *on the surface;* thus, if any insulated conductor have another electrified

Fig. 16.

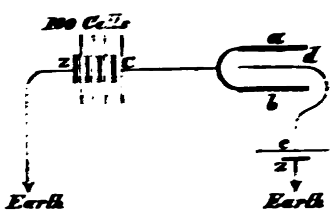


body brought near to it, it is well known that the electricity in it will be disturbed according to well-understood laws of electrical induction, and one side of it will become charged positively and the other negatively; for example, in fig. 16. A is a globe charged with positive electricity and brought near to another insulated globe B; the effect is, that the distribution of the natural electricity in B is disturbed, and the side *c*, nearest to A, becomes in ordinary language *negatively electrified*, and the opposite

side, *d*, *positively electrified*; but here let the student carefully consider what these terms mean as usually employed by writers on static electricity; they mean that there is a *larger quantity of free or induced electricity* on the side *d*, and a smaller quantity on the side *c*; they treat of the distribution of the free electricity, or the *charge* as it is called, but do not usually refer to electrical tension at all. As regards the tension, the fact is that it is equal everywhere throughout B. There is less electricity at *c* than at *d*, but *the tension is precisely the same at one point as the other*; if it were not so, a wire connected from *d* to *c* would convey a current from one point to the other, which we know is not the case. In short, *the tension throughout all parts of a conductor is uniform, or rapidly tends to become so.*

As a further illustration of the importance of not confounding a positive or negative *charge* with positive or negative *tension*, we will give a paradoxical case in which a body is *negatively* electrified, and is charged with negative electricity, and yet has a *positive* tension.

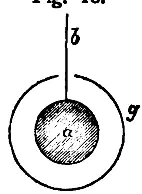
Fig. 17.



In fig. 17, *a b* is a bent plate, connected to the positive

pole of a battery of one hundred cells, and having therefore a positive tension of one hundred. It entirely envelops the plate *d*, which is in connection with the positive pole of a battery of one cell. The positively-charged plate *a b* acting inductively on the plate *d* gives it a *negative* charge as regards its free electricity; but the cell with which it is connected gives it a *positive* tension of one cell, as regards its tension, and thus we have the apparent paradox of a body negatively electrified, or having less than its natural amount of electricity, but which has yet a positive tension, and is prepared to give off a continuous stream of electricity to the earth. This experiment is more easily demonstrated with a length of cable immersed in an insulated tub of water, as described in the next chapter; the water being raised to a tension of one hundred, and the cable to any smaller tension.

Fig. 18.



While treating on tensions as affected by induction, another instructive case may be referred to: *a* in the figure is a ball suspended within the interior of a conducting globe *g*: if this outer globe be now raised or lowered to any tension, as, for example, 100 plus or

minus, the ball *a* will also assume the same tension: this arises purely from induction, and all the changes which occur in *g* are instantly reproduced in *a*, without any alteration of the *quantity* in *a*, and without any electricity passing from one to the other. If *b* be a fine wire, it is easy to verify this by measuring the changes on an electrometer: if, before starting, *a* have a charge given to it equal to a tension of, say ten volts* plus or minus, this difference of ten volts will remain constant throughout all subsequent changes.

* The volt is a measure of tension, see p. 43.

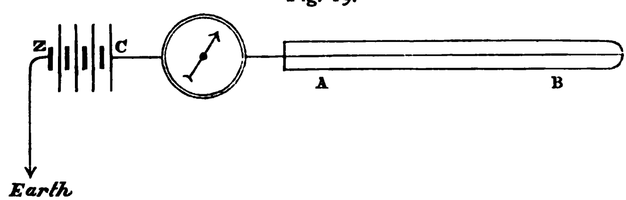
CHAPTER IV.

On Electrical Induction.

Although the phenomena of induction enter more or less into every case of electrical action, they rarely come within the cognizance of those who have charge of land lines. An allusion was incidentally made to the subject in the last chapter, and a few of its laws will be briefly given here for the benefit of those who may have charge of underground wires, or cables.

If a cable A B (fig. 18), perfectly insulated with gutta

Fig. 19.



percha or other dielectric, be immersed in water or buried in the earth, and a galvanometer and battery be connected to it, as shown in the diagram, at the first moment of contact a certain charge of electricity will be seen to rush into the cable, causing a momentary deflection of the needle. After this all remains quiescent, and the cable remains charged throughout its length to the

full tension of the battery; but if the insulation be perfect, no more electricity enters the cable. This is called the charge, and its amount varies *directly as the tension*; that is to say, with a tension of ten cells it is exactly ten times as great as with one. If the battery be now removed, and the inside of the cable connected to earth, the whole of the charge will return through the galvanometer to earth, deflecting the needle to the same extent as before, but in the opposite direction: this is called the discharge, and its amount is exactly the same as that of the charge.

If a perfectly insulated mile of cable be charged to a tension of, say ten, and then joined to a similar length of one mile, the charge will instantly distribute itself uniformly throughout the whole two miles, and the tension will be reduced to five; and so if it be joined to a length of nine miles, the tension will be one-tenth of what it was before; but the *quantity* will be the same in the ten miles as it was in the one, and will remain quite unaffected by the change in tension: the quantity per mile will of course be one-tenth of what it was at first. The student will perceive that we are here for the first time applying the term quantity to a static charge, and not to current electricity.

If a charge be sent into a cable in the manner before described, a precisely similar quantity of electricity *of the same kind* leaves the outer surface and becomes distributed in the earth. Thus if three Daniell's cells be connected to a mile of ordinary submarine cable, a charge of

about one farad of electricity will enter the cable, and if so, exactly one farad of electricity will leave its outer surface and flow into the earth : the outer surface is then said to be *negatively* electrified, for it has less than its natural amount of electricity. In the same way, if the negative pole of the battery had been applied to the cable the charge would have been negative, that is to say, the cable would have one farad less than its natural amount, and the outer surface of the cable would have attracted one farad of electricity from the surrounding earth, and would have been *positively electrified.* But in either case these terms must not be understood to refer to the tension of the exterior, but only to the quantity of electricity collected there : whatever the tension of the interior may be, that of the exterior is neither positive nor negative, but remains rigidly zero. If the cable thus charged, that is to say with a negative charge and a negative tension inside, and with a positive charge and zero tension outside, be lifted out of the water, its exterior charge will come with it; and if it be dried, or scoured, or washed, or treated in any way, this charge cannot be removed from the surface, nor can its presence be in any way detected or made evident to the senses : it remains, in fact, latent, and only when its counterpoising charge in the interior is removed does it spring again into activity and become once more electricity of tension.

If, instead of raising the tension of the inner wire of the cable, we raise the tension of the water in which it is

immersed, the same phenomena take place, that is to say, a charge - corresponding to the tension of the exterior goes out of the cable (deflecting the galvanometer to precisely the same extent as if it had been connected to the interior), and the inside becomes negatively electrified, that is to say, negative as regards the quantity of electricity in it, but absolutely at zero as regards its tension.

The quantity of the charge depends on the difference of tension between the interior and exterior, and not on its degree: thus, if the exterior water have a tension of ten cells, and the cable of thirteen, the charge is the same as if the water were at zero and the cable at three.

We have already seen at fig. 8 that the positive tension in a long telegraph line falls regularly from the battery to the distant extremity of the line; or, if the charge be negative, it rises regularly from the battery to the end of line, and this directly in proportion to the distance. Now since the charge varies everywhere as the difference between the internal and external tensions, it follows that there is a constantly decreasing charge as we get further from the battery; in fact, the diagram at fig. 8 would represent the charge as accurately as it does the tensions.

If the line be divided into any number of equal portions, the proportion of charge in each length, commencing at the distant end, will be as the numbers 1, 3, 5, 7, 9, 11, &c.; and consequently, if the line be divided into two portions, the quantity of the charges will be as one to three respectively, or the half near the battery will contain thrice the charge that the more distant half contains.

The quantity of electricity contained in any given cable* is called the *electrostatic capacity*, or sometimes the *inductive capacity*. The length being constant, it depends on the proportion between the surfaces of the copper conductor, and of the *dielectric* or insulating material; it scarcely alters with temperature, but it differs with different substances. It is about twenty-five per cent. greater with gutta percha than with india rubber and its compounds. Increasing the copper conductor increases the quantity, and increasing the thickness of the dielectric or insulating substance diminishes it; in fact, the gutta percha behaves in the same manner as air. Land lines have so little charge because the thickness of the coating of dielectric (which is in this case air) is so great. If we double or treble the diameter of the copper, and also that of the gutta percha, the quantity remains unchanged. We obtain in that way a cable having four or nine times as heavy a conductor with the same inductive capacity.

The electrostatic capacity of any insulated wire is inversely proportional to the logarithm of $\frac{D}{d}$, where D is the diameter of the dielectric or insulator and d that of the conducting wire. Thus the diameter of the copper in the Atlantic cable is 147 thousandths of an inch, and of the gutta percha 467, and $\frac{467}{147} = 3{\cdot}177$; and the logarithm of $3{\cdot}177$ is $\cdot 5020$, which is the logarithm required.

A short table of logarithms is given in the Appendix for reference; and we give below the dimensions and

* With the unit tension of one volt, see p. 36.

logarithms of two or three cables, and their calculated inductive capacity: the diameters are given in inches:—

Name of Cable.	Diam. of Copper. d	Diam. of Percha. D	Logarithm of $\frac{D}{d}$	Calculated Electrostatic Capacity.
				Farads.
Malta and Alexandria	·153	·463	·4809	·3903
Atlantic Cable . .	·147	·467	·5020	·3739
Persian Gulf Cable .	·110	·380	·5384	·3486
No. 1 Gutta-percha wire	·65	·289	·6480	·2896

The electrostatic capacity of the Persian Gulf cable is ·3486 farads,* and from this datum we can, by means of the logarithm, calculate the capacity of any other cable. For example, the logarithmic equivalent for the Atlantic cable is ·5020, and that of the Persian Gulf is ·5384; and since the inductive capacity varies inversely in this proportion, we have for the Atlantic cable—

$$\cdot 5020 : \cdot 5384 :: \cdot 3486 \text{ farads} = \cdot 3739 \text{ farads.}$$

The rule, in fact, is this: as the log. of the new cable is to that of the Persian Gulf cable, so is ·3486 farads to the answer. It will be observed that the capacities in all cases are about one-third of a farad per mile, and also that the larger the logarithmic number, the smaller is the capacity of the cable.†

* See pages 36 and 43.

† The following is a still simpler formula:—

$$\text{Electrostatic capacity} = \frac{\cdot 18769}{\text{Log. } \frac{D}{d}} \text{ farads.}$$

The obtaining of the logarithmic equivalent can be done more easily by the following method than by that previously given :—

Subtract the logarithm of the smaller diameter *d* from that of the larger diameter D, and the remainder will be the logarithmic number required. Thus in the instance above given we have—

Log. of 467 = ·6693
Log. of 147 = ·1673

Logarithm required ·5020

It will sometimes happen that the decimal part of the logarithm of the smaller diameter *d* will be larger than that of D; the subtraction is nevertheless performed in the same way, borrowing ten in order to make the left-hand figure of D large enough for subtraction, and disregarding all remainder.

This formula has another value: the logarithmic number not only represents inversely the proportionate inductive capacity of different cores, but it also represents their *insulation* or resistance; and that in a direct ratio, the larger the logarithm, the higher the resistance. Thus, assuming the quality of material the same, the Persian Gulf core would give a higher resistance than the Atlantic core in the proportion of 5384 to 5020.*

* As 5384 : 5020 : : res. P. Gulf : res. Atlantic. A still simpler formula is the following :—Res. per statute mile of any gutta-percha cable $= \dfrac{\text{Log.}\ \frac{D}{d}}{13}$ megohms. (See Appendix.)

We saw at page 29 that the quantity of charge in a cable was proportionate to the tension, and at page 17, that the leakage or escape of electricity through any conductor was also proportional to the tension. It arises from this that a cable charged to a tension of two hundred cells should fall to a tension of one hundred, in the same time that it would fall from one hundred to fifty, or from fifty to twenty-five; the escape per minute decreasing just as the tension decreases. We know also that the length of the cable does not affect this result; a cable one mile long would fall to half its tension in the same time as it would if it were one hundred miles long.

Lastly, we have just seen that the greater the inductive capacity of a cable the smaller its resistance, or, in other words, the greater its leakage. If we combine these three laws we arrive at a somewhat curious general result, viz., that at any given temperature, all gutta percha cables should lose a given proportion of their charge by leakage; for example, they should fall from any tension to half that tension in a uniform time; and this irrespective of their length, or of the size of their conductor, or of the thickness of their insulating coating, or of the battery power employed.* In practice, the time of falling from charge to half charge is found to be a very useful method of comparing the insulation of a cable at different periods of time. In fact, with extremely long cables it is the only reliable method.

* See page 98.

CHAPTER V.

On Electrical Quantity.

THE meaning of this term has by this time become apparent; it has been applied to current electricity, where it has been spoken of as a current of so many farads per second; and it has been spoken of as static quantity, as an absolute static charge of so many farads. If a cable contained a static charge of sixty farads, and the whole charge were to flow out at a uniform rate in one minute, we should have a current of one farad per second. Ordinary telegraph cables usually have an "Electro-static capacity," as it is termed, of about one-third of a farad, that is to say, with the unit tension (which is a little higher than that of one Daniell's cell) they contain a charge of about one-third of a farad per nautical mile. Consequently, one mile of cable, with a tension of one hundred and eighty cells, would take a charge of about sixty farads, and would, if discharged during one minute at a uniform rate, maintain a current of one farad per second.

The importance which attaches to quantity lies in the fact that *the influence of any electric current upon an electro-magnet or galvanometer needle varies with the quantity of the current passing round the coil:* hence, if by any means we can get a greater quantity of current to pass round our coil, we get our magnet or needle deflected with a greater force. One obvious way of doing this is to increase our electromotive force, and consequently our tension: if we double this we get double the current through our coils. Another usual expedient where we have much resistance in the circuit, is to make the coil wire circulate round the needle or magnet a great many times, sometimes many thousand times, and each revolution adds its influence to that of the others. We are obliged, however, in this case to use very fine wire, or else the outer coils get out of influence from their distance, for a long length of very small wire interposes very great resistance, and therefore diminishes the quantity. On short lines, where the resistances are small, it is most convenient to use a few turns of very thick wire; and with a suitable battery it is easier to get a much larger quantity of electricity to pass round a coil through half a dozen turns of thick wire, than through six thousand turns of thin wire, and hence to get a stronger deflection of the needle or of the electro-magnet.

It may be as well to remark here that the French writers on electricity use the word *intensité*, as applied to currents, in the same sense that we have used quantity; and English translators frequently render the term by the

word "intensity:" readers of French books or their translations should therefore bear this in mind, and remember that when the term "intensity" is applied to electric currents, it usually has no relation to tension, but should be understood to mean the quantity per second, or strength of the current.

Not only does the influence of the current upon the needle or electro-magnet depend on the *quantity* of the current without any reference to its tension, but, generally speaking, all the most important effects of electricity vary in magnitude as the quantity rather than as the tension. The quantity of water or other substance decomposed in a cell, or of metal deposited on an electrotype plate, depends purely and only on the quantity of current which passes through the cell. A battery of five hundred cells will scarcely decompose more than a single cell, and if resistances be interposed so as to make the quantity of current the same, it will not decompose any more.

Faraday stated that a flash of lightning contains so small a quantity of electricity that it probably would not suffice to decompose more than a single drop of water; its enormous tension would be wasted, and only converted into heat. There is one sense, however, in which this statement would not be strictly accurate. Assuming the tension of the lightning to be a million of cells, and assuming the tension of one cell to be sufficient to decompose water, it is clear that by passing the flash through a million vessels of water in a series we should have tension enough to decompose a drop of water in

each vessel, and thus decompose a million drops. In like manner, our battery of five hundred cells would deposit metal or decompose water in, say five hundred successive vessels, losing a tension of one in each vessel; but in both these cases the quantity formed or decomposed would be precisely the same in each of the successive vessels, and would depend only on the quantity which had passed through them, without any reference to the tension, which, as we know, would be much greater at one end of the series than at the other.

In like manner, the amount of heat generated at any point, or in any part of a circuit, varies as *the quantity of electricity passing multiplied by the difference of tension*, or (since these two things always vary in the same ratio) as the square of the quantity of electricity passing.

An electric spark is a minute quantity of electricity leaving a conductor at a high tension, and falling in tension as it travels through the air, and giving out heat and light at each point in proportion to the loss of tension. A spark of electricity five or six inches long, from an electrifying machine, contains so small a quantity that it may be received on the knuckle with impunity, but if a larger quantity be accumulated in a Leyden battery to the same degree of tension, the shock would destroy an ox.

CHAPTER VI.

On Earth Connections.

In most of the experiments hitherto described the battery has had one pole to the earth, and the distant end of the line has been placed to earth; and even in experiments performed in the room the terminations of the arrangement have been, for the sake of perspicuity, drawn and described as being connected to the earth. In practice, however, this is not generally necessary, most of the indoor experiments being equally well performed on the table without any earth connection. Wherever it is preferred to use the earth connection in order to insure a tension of o as a starting point, a single wire connected to any gas pipe, or to moist earth, will serve for any number of earth connections.

The earth, being regarded as an inexhaustible reservoir of electricity, offers no sensible resistance to the passage into it, or out of it, of any quantity of electricity, in the same way as the ocean would supply or receive at any point an indefinite quantity of water; and this is equally

true whether the points be close together or in different parts of the globe. The earth is not, however, always or even usually at the same tension at different points, and consequently currents are almost constantly circulating through the earth, and also through the telegraph wires, in their endeavours to equalise the tension. These are sometimes so considerable as to show the existence of a difference of tension of fifty or one hundred cells and upwards between places not more than one or two hundred miles apart. Such currents are, in fact, sometimes sufficient to deflect the needle of the mariner's compass considerably: these extreme cases, however, only occur during the prevalence of aurora, and are very probably caused by the induction of the vast clouds of electricity which are at such times seen travelling in the upper regions of the atmosphere, and which, during their passage over any part of the earth's surface, repel and chase away by their induction the natural electricity at that spot, thus causing temporary electric currents and changes of tension. In such cases the telegraphist, where possible, joins two parallel line wires together into one circuit, without any connection with the earth, and becomes thereby quite independent of its tensions.

In practice it is found that the earth connections, made at stations where there are no gas or water pipes, are often defective, and offer great resistance to the passage of the current; this is especially the case in dry seasons and dry countries. The earth connections should therefore be carefully looked to occasionally. If a station

have a defective earth, and have two wires leading to it, the evil will generally disclose itself; for the current from a distant station, finding a great resistance at the earth plate, will partially return along the second wire, and will exhibit feeble signals on the return wire, both at the faulty station and at the station which sends the current. Where, however, there is only one wire to a station, the evil is not so easily apparent, and may exist for years, and cause bad working without discovery: the measurement of the resistance of the circuit would disclose it, if the evil were extreme, and this might be taken from either station. The better way of discovering it is, however, to run a naked wire for a few hundred yards to the nearest water or damp earth, and to connect it to the line wire, interposing the galvanometer: if the earth offer any sensible resistance, a portion of the current received from a distant station will pass through the new earth and show itself by slightly deflecting the galvanometer, which would not be the case if the earth were perfect.

CHAPTER VII.

On Units of Measurement.

THE measures now universally adopted are those of the British Association.

1. **The unit of resistance** is called the *ohm*. One million ohms = 1 *megohm*, and one millionth part of an ohm = 1 *microhm*.

Before the use of the "British Association units," or ohms, resistances were generally measured in Siemen's units or Varley's units; 1·0456 Siemen's units are equal to one ohm. *To convert Siemen's units into ohms, multiply them by* ·9564. One Varley's unit is equal to about twenty-five ohms.

The ohm is a resistance equal to 10^7, or ten million absolute electromagnetic units, and the megohm is equal to 10^{13} absolute units. The ohm is often called the B. A. unit.

2. **The unit of tension**, or *electromotive force*, is called the *volt*, and it does not differ greatly from that of a Daniell's cell. One million volts = 1 *megavolt*, and one millionth of a volt = 1 *microvolt*. According to

the latest determination by Sir William Thomson, the volt = ·9268 the electromotive force of a Daniell's cell, or the Daniell's cell = 1·079 volt.

The volt is equal to 10^5, or 100,000 absolute electromagnetic units of tension.

3. **The unit of quantity** is called a *farad.* One million farads = 1 *megafarad*, and one millionth of a farad = 1 *microfarad.* The farad is that quantity of electricity which, with an electromotive force of one volt, would flow through a resistance of one megohm in one second; and since the quantity passing varies inversely as the resistance, the megafarad is that quantity which would flow through a resistance of one ohm in one second (see p. 36).

The farad is equal $\frac{10^5}{10^{13}}$, or $\frac{1}{100,000,000}$th part of the absolute electromagnetic unit of quantity. The megafarad, or quantity which flows through one ohm with one volt in one second, is $\frac{1}{100}$th part of the absolute unit.

4. **The unit of current.**—The current of electricity is defined as the quantity of electricity which flows per second. The British Association unit of current is a current of one farad per second, or that which would flow through one megohm with a tension of one volt, or through one ohm with one microvolt; it is equal to 10^{-8}, or $\frac{1}{100,000,000}$th part of the natural electromag-

netic unit of current, or the unit tension, through the unit resistance.*

5. **The unit of work or dynamity.**—The natural unit of force in metrical measure is that which will produce a velocity of one metre per second in a mass weighing one gramme (15·43 grains) after acting on it one second of time. Gravity would move a gramme through 9·808 metres in a second; therefore the natural

mean sea level, latitude 45° is 9.80533

unit of work is $\frac{1}{9{\cdot}808}$ of a gramme raised one metre in one second. The conventional unit of work W ordinarily employed in metrical measure is, however, that which will raise a weight of one gramme one metre in one second, and is called the *metre-gramme* unit, and is of course equal to 9·808 absolute units of work.

* A unit current is one which, in a wire one metre long, bent so as to form an arc of a circle of one metre in radius, or, which is the same thing, an arc of 57¼°, would repel a unit pole at the centre of the circle with a unit of force. The whole circumference of a circle, a metre in radius, is 6·2832 metres, and would consequently repel a unit pole at its centre with 6·2832 units of force. If such a circle be placed in the magnetic meridian, the deflection produced by it on a small needle at its centre, as in the tangent galvanometer, is due to the whole circumference, so that the strength of the current, measured by only one metre of it, forms only $\frac{1}{6{\cdot}2832}$ part of the deflecting force. A unit current in a straight wire, measuring a metre, repels another similar unit current, one metre distance, with a unit of force. A unit magnetic field repels a metre's length of a unit current held at right angles to the lines of magnetic force with a unit of force. Hence in a unit magnetic field, a metre of a unit current, forming an arc of 57¼°, and held in the magnetic meridian, would cause a small needle at its centre to deflect 45°.—*Ferguson's Electricity.*

The work done is equal to the quantity of any current per second multiplied by its fall of tension or difference of potential; it therefore varies as the number of farads multiplied by the number of volts. The absolute unit of work = 1000 volt-farads. The conventional or metre-gramme unit of work W = 9808 volt-farads per second, or 9808 farads falling through a tension of one volt.

6. **The unit of heat** H is taken as one gramme of water raised 1° centigrade. The mechanical equivalent of this unit is 423·8 metre-grammes, or grammes' weight raised one metre (Paris), or H = ·423·8 W. It is equal to 4157·25 absolute units of work. It is proportional to the quantity of electricity multiplied by its fall of tension.

7. **The electro-chemical unit.**—It is found by experiment that a unit quantity of current decomposes ·142 grains of water, or generates 1·02 cubic inches of mixed gas per second, the amount of zinc consumed in each cell being ·513 grains. The chemical equivalent of zinc being $\frac{32 \cdot 5}{9}$ that of water.

One grain of zinc consumed in a Daniell's battery performs 195,000 metre-gramme units of work, and one grain consumed in a Grove's battery performs 365,000 units of work. (See also p. 115).

The tension necessary to decompose acidulated water is about 1·75 volts.

CLARK'S DOUBLE-SHUNT DIFFERENTIAL GALVANOMETER.

THIS instrument is a form of differential galvanometer, that is to say, it is wound with two separate wires which form distinct circuits around the needle; one circuit extending from A to B and the other from C to D.* These wires are both adjusted to have the same electrical resistance, and also to have the same effect on the needle, so that when a battery is connected to the two central terminals B and C, the current divides itself into two equal portions; one flowing from B to A and tending to deflect the needle to the left, the other from C to D deflecting it to the right; but since the quantities and forces are precisely equal, the needle remains quiescent: if equal resistances be added on each side of the galvanometer the needle still remains motionless, but if unequal resistances be added, more electricity flows to that side which has the lesser resistance, and the needle is deflected to that side. The peculiarity of the instrument consists

* See Diagram of connections, Frontispiece.

in the addition of a "shunt," or derived circuit, to each half of the galvanometer: these shunts are marked on the instrument "shunt $\frac{1}{100}$:" they are short wires having a resistance equal to exactly $\frac{1}{99}$th of that of the half coil, and when thrown into the circuit by the insertion of the plug, $\frac{99}{100}$ths of the current pass through them, and only $\frac{1}{100}$ through the coils of the galvanometer: either one or both half coils may be shunted at pleasure. The instrument is supplied with a set of resistance coils varying from one to ten thousand ohms.

The instrument does not pretend to minute accuracy, but is well suited for making all the ordinary practical measurements required in telegraphy. Its daily and hourly use cannot be too strongly recommended; for a constant reference to actual measurement is the very foundation of telegraphy. The resistance of every principal circuit should be measured every morning, and its variations recorded. In England it is generally considered that even in bad weather a line should not give less than one megohm (one million ohms) per mile, so that a line of two hundred miles should give not less than $\frac{1,000,000}{200} = 5000$ ohms. If it gives less than this, the low resistance is due to defective insulation. The line should now be tested in many separate sections, either from the office (see Chapter I.) or by a visit to each section. If the resistance per mile is the same for each section the fault is probably in the nature of the insulation, but if, as is usual, some sections are very much

worse than others the fault will probably be found in tunnels, in contact from branches of trees, from wires or insulators touching the posts, from broken insulators, &c., and a visit to the faulty locality will at once disclose the cause of the evil.

The metallic resistance of the line wire should also be occasionally tested in sections in the finest weather: if there is a uniformity in the sections all is well, but if some give an unduly high resistance per mile, a closer examination will almost certainly disclose imperfectly-soldered joints, which oppose a great resistance to the current and interfere seriously with the working; or the earth connections may be out of order. It is difficult for those who have not tried it to believe the improvement that may be made in any line in a few days by quantitative measurements, and by an inspection of the sections which give indications of being defective.

In the same way each battery should be tested for resistance every few days, and those which are faulty should be attended to. The operation is performed in a few moments, and it will frequently be found that one dry or defective cell or battery is sufficient to mar the working of a whole line.

CHAPTER VIII.

To use the Instrument as an ordinary Galvanometer.

PLUG up B and C and attach the line wire and earth to the terminals A and D. The current then passes through half the coil from A to B, thence along the front bar to C, and through the other half coil from C to D. The instrument is now in the condition of an ordinary "detector," and is suited for receiving a current, proving the continuity of a circuit, or detecting a broken connection or loss of insulation in any apparatus. For these purposes the instrument may sometimes with advantage be inclined on its back support.

CHAPTER IX.

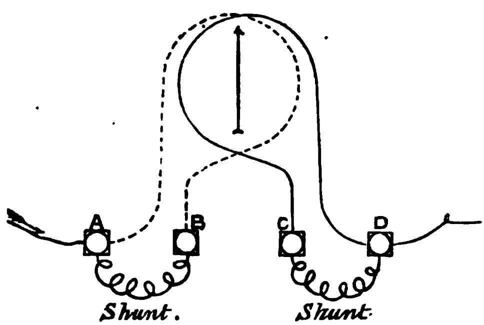
To use the Instrument as a Sending and Receiving Instrument.

PUT the line to the terminal marked "key," at the back of the instrument; the battery to one of the small screws on the front bar (the other pole being to earth); connect the terminal marked "bridge" by a wire to A, and put D to earth; lastly, connect a short wire from B to C by means of the flat-headed screws. In this condition, when the key is pressed down, the battery current goes direct from the front bar through the key to line without passing through the instrument. When the key is resting up against the bridge in its normal position, the current received from the line passes from the key through the bridge to its terminal, and thence by the connecting wire to A, and through the galvanometer to D and earth.

If it be preferred that both the transmitted and received current should pass through the galvanometer, the connections are a little varied: join the battery as before to the front terminal and connect a short wire from B to C as

before; connect a wire from the "key" terminal to A, put the line to D and put "bridge" to earth. In this condition both currents pass through the galvanometer. On emergency the instrument may be used as a receiving instrument by inclining it on its support, and by extemporising stops out of pieces of wood or wire to limit the movement of the needle.

Fig. 20.



CHAPTER X.

To use the Instrument as a Quantity Galvanometer for Testing Batteries.

INCLINE the instrument and insert both the plugs marked "shunt $\frac{1}{100}$;" insert plugs at B and C, and connect the poles of the battery to be tested at A and D, and observe the deflection. The instrument is now connected up in the manner shown at fig. 20, and is adapted for measuring much stronger currents, and also for testing the condition of batteries. Ascertain the average deflection from a battery cell in good condition, and then if any of the cells fall much below the average standard it is a proof either that they offer too great internal resistance or that the electromotive force is become feeble, and in either case they should be rejected. In this condition the instrument will give nearly the same deflection with one cell as with ten cells or one hundred cells, and it is sometimes convenient to test a whole battery at once instead of by single cells; the influence of a bad cell is not, however, so marked when associated with other cells as when tested singly.

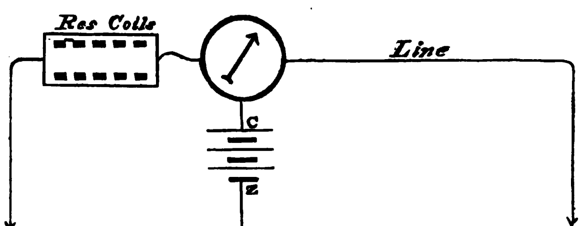
The testing of the individual cells may be done while the battery is in use.

CHAPTER XI.

The Measurement of Resistances.

To measure any resistance by direct measurement, insert plugs at B and C, and connect the line to terminal A;

Fig. 21.



put the battery to the terminal marked "key," and the resistance coil to D, their other ends being to earth. On depressing the key, the battery current divides itself into two parts, one part traversing half the galvanometer from B to A, and through the line to earth; the other part

traversing the other half, and through the resistance coil to earth. If the resistance of the coil and the line are equal, the needle will remain motionless; if they are not equal, the needle will incline to one side or the other, and the resistance must be varied till it remains unaffected. The resistance unplugged will then equal that of the line. If extreme accuracy be desired, it is advisable to repeat the measurement, changing the line and resistance coil to opposite sides, and taking the mean of the two measures.

CHAPTER XII.

The Measurement of higher Resistances.

THE resistance coils only range as high as ten thousand ohms, and this, therefore, is the limit of their measurement by the above plan. If it be necessary to measure higher resistances, insert a plug between D and the block marked "shunt $\frac{1}{100}$," all other connections remaining unchanged. That portion of the current which traverses the right-hand half of the galvanometer and the resistance coil will now be divided into two parts, $\frac{99}{100}$ths traversing the shunt and $\frac{1}{100}$ passing through the galvanometer; it follows, therefore, since only $\frac{1}{100}$ of its current affects the right-hand portion of the galvanometer, while the whole of its current affects the left hand, that in order to produce no movement on the needle, one hundred times more electricity must pass to the right hand than to the left, or, in other words, the resistance of the right-hand circuit must be one hundred times less than that of the left. Hence the resistance unplugged on the coil must be multiplied by one hundred to give the true resistance of the line. By this method it is possible to measure resistances as high as $100 \times 10{,}000$ ohms, or one million ohms (one megohm).

CHAPTER XIII.

To Measure very high Resistances.

If it be necessary to measure still higher resistances, the following plan may be resorted to: Put the line to A and the battery to D (its other pole being to earth), and insert plugs at B and C. Note carefully the deflection, the battery power being so arranged as to make this, if possible, about 30° or 40°. Now disconnect the line and insert in its place a resistance coil with its other end connected to earth. Insert both the $\frac{1}{100}$ shunt plugs at A and D, and reduce the number of battery cells to, say, the tenth of its original number; then, by varying the resistance coils, reproduce exactly the same deflection as before. This being the case, it is manifest that the same quantity of electricity is passing through the galvanometer coils as before; but since the shunts convey $\frac{99}{100}$ of the whole current, and therefore diminish its effect one hundred times, and since the battery power is also diminished ten times, we have to multiply the reading of the resistance coil by 100 × 10, or one thousand times. By this method

we can measure resistances as high as 1000 × 10,000 ohms, or ten million ohms (ten megohms). For example, suppose a line to have a resistance of 8,450,000 ohms; this would give the same deflection with one hundred cells direct as a resistance of 845 ohms through the shunted galvanometer with one cell, or as 8,450 ohms with ten cells. To obtain theoretical accuracy by this method the resistances of the batteries ought also to be taken into account, but this may be safely neglected in practice.

CHAPTER XIV.

To Measure the Resistance of Short Wires, &c.

For measuring small resistances, such as one ohm or less, the arrangements are the same in principle as in Chapter 12; that is to say, attach the wire to the terminal A, and one pole of the battery to the "key" terminal; attach the resistance coil at D; plug up B and C, and also the $\frac{1}{100}$ shunt at A; finally, attach the other pole of the battery and the other end of the wire to be measured direct on to the opposite end of the resistance coil *without using any intervening connecting wire.* Press down the key, and, when the resistance has been varied so as to bring the needle to zero, it will be found that the *resistance of the wire is* $\frac{1}{100}$ *of that unplugged in the resistance coil.* It therefore transmits one hundred times more current; but since the effect of this is diminished one hundred times by the shunt at A, the effect on the needle is nil. This arrangement is very useful for determining the specific conductivity of specimens of copper and other metals.

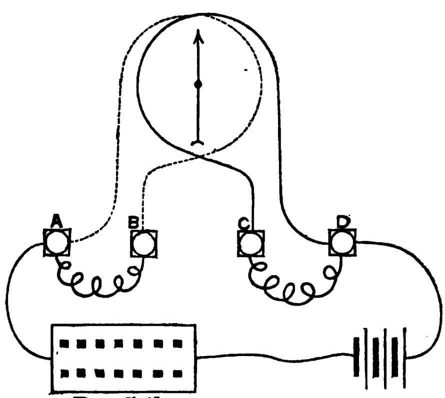
CHAPTER XV

To Measure the internal Resistance of Batteries.

CONNECT the battery and a resistance coil in circuit between the terminals A and D, and insert plugs in the resistance coil so that it gives no resistance; insert plugs at A and C, and also both the shunt plugs at A and D. The battery current will now flow through one half of the galvanometer circuit only, being however reduced to $\frac{1}{100}$th of its amount by the shunt D: the deflection of the needle must be carefully read. The plug A must now be removed to B, which causes the battery current to flow through both halves of the galvanometer (each being shunted). The circuit will now be as shown in Fig. 22, and the needle will, of course, be deflected somewhat more than before. Now unplug the resistance coil which is in circuit with the battery until the deflection of the needle is reduced to its original amount, and the resistances unplugged will be equal to the internal resistance of the battery. For example, assuming the resistance of the half coil to be ninety-nine ohms, and that of the shunt

wire one ohm, the joint resistance of the two circuits will be: $\dfrac{\text{Galvanometer} \times \text{Shunt}}{\text{Galvanometer} + \text{Shunt}}$ or $\dfrac{99 \times 1}{99 + 1} = 0{\cdot}99$ ohms. Suppose the resistance of the battery to be four ohms, the two together = 4·99 ohms, and the current acts on the galvanometer needle through one half of its circuit

Fig. 22.



only: when the second half of the galvanometer is thrown in circuit by shifting the plug from A to B, the resistance becomes 4·99 + 0·99 = 5·98, and therefore less current passes; but, since it acts upon the needle through both coils instead of one, the deflection is greater than before. The resistance coil is now varied until the needle recedes to its original deflection, which will necessitate the un-

plugging of a resistance of four ohms, making the total resistance now $5 \cdot 98 + 4 = 9 \cdot 98$, which is exactly double the first resistance; that is to say, in the one case we had the current acting upon one coil through 4·99 ohms, and in the other case acting upon the two coils through 9·98 ohms, the deflecting power on the needle having been increased in the same ratio as the resistance.

Other methods of obtaining the resistance will be found in the Appendix.

CHAPTER XVI.

To determine the Electromotive Force of a Battery.

THIS can only be done relatively in terms of some other standard battery. The method is as follows:— Determine the resistance of the standard and of the other cells to be measured; insert the shunt plugs at A and D, and also at C and B, as in the former case, and join up the standard cell in circuit with a resistance coil to the terminals A and D, and unplug resistance until a convenient deflection is obtained, say 15°; note the sum of the resistances in circuit, including that of the battery, galvanometer, resistance coil, and connecting wires; now change the cell for another, and by unplugging the resistance coils bring the needle again to the same deflection, 15°: having again found the total resistance in circuit, the relative electromotive forces of the two cells will be directly proportional to these resistances.

A table of the electromotive forces of different batteries will be found in the Appendix. 105

CHAPTER XVII.

To ascertain the Specific Conductivity of Copper.

THE specific conductivity of pure copper is taken at 100; but the copper used in telegraphy being never absolutely pure, has a lower conductivity, or, in other words, gives a higher resistance: when carefully selected its conductivity usually ranges from 85 to 95 per cent. of that of pure copper.

One nautical mile (2029 yards) of pure copper, weighing 1 lb., has a resistance of 1155·5 ohms at 60° Fahr., or of 1192·3 ohms at 75° Fahr. From these data we can easily calculate the resistance of any other wire of pure copper by dividing the above resistance by the number of lbs. weight per mile. For example, a wire weighing 180 lbs. per knot should, if pure, have at 60° Fahr. a resistance of $\frac{1155{\cdot}5}{180}$, or 6·417 ohms per mile; and if its length were $3\frac{1}{2}$ miles its resistance should be $3{\cdot}5 \times 6{\cdot}417 = 22{\cdot}26$ ohms. If, however, the wire be impure, and we measure its actual resistance by the

methods described at p. 54 or 59, and find it to be, say 26 ohms, we know that its conductivity is less than that of pure copper in the inverse ratio of the resistances; that is to say—

$$26 : 22{\cdot}26 :: 100 : 85{\cdot}6;$$

or the copper has a conductivity of 85·6 as compared with pure copper.

For short lengths of wire the following data are more suitable:—*A wire of pure copper, one inch in length, weighing one grain, has a resistance of* ·001516 *ohms at* 60° *Fahr.*, and the resistance of any other wire of pure copper, at 60° Fahr., will be $\frac{\cdot 001516 \text{ ohms} \times \text{square of length}}{\text{Weight in grains}}$, the length being taken in inches. To understand this formula, imagine the above wire to be stretched to twice its length, without any alteration in its weight: being twice as long as before, its resistance from this cause must be twice as great; but since it has been stretched it has evidently been reduced to only half its original size or sectional area; its resistance therefore must be again doubled from this cause. The wire will therefore have 2 × 2, or four times its original resistance; and similarly, if stretched to three times its length, it would have 3 × 3, or nine times its resistance. In other words, the weight being constant, *the resistance of a wire varies as the square of the length.*

Let us now suppose the wire to retain its original length, but to be double in weight; the wire having twice the substance that it had before will evidently have

only half the resistance, and if it had four times the weight it would have only one-fourth the resistance. In other words, ***the resistance of a wire varies inversely as the weight.*** Compounding these two rules together, we get the before-mentioned formula for the resistance of any wire of pure copper, viz. :—

$$\text{Resistance} = \frac{\cdot 001516 \times L^2}{W.}$$

Having, therefore, calculated the theoretical resistance of any wire, we have only to compare it with the actual resistance, as before, to give its conductivity.

Thus 25 inches of wire, weighing 360 grains, should give a resistance of $\frac{\cdot 001516 \times 25 \times 25}{360}$ ohms, or ·263 ohms; but if it actually gives a resistance of ·290, the conductivity of the copper will be—

$$\cdot 290 : \cdot 263 :: 100 = 90 \cdot 7 \text{ per cent.}$$

CHAPTER XVIII.

Allowance for the Effect of Temperature on the Conductivity of Copper.

WE have hitherto neglected the effect of temperature, and spoken of resistances only at a temperature of 60°; but since the resistance of copper increases ·21 per cent. for every degree Fahr., while the German silver of the resistance coils scarcely changes perceptibly (about ·024 for each degree Fahr.), it is necessary to make allowance for this. For instance, in the first example the resistance of the 3·5 miles of pure copper was calculated as 22·26 ohms, at 60° (page 64); but if the actual temperature at the time had been 90°, we should have to add thirty times ·21 per cent. to the 22·26 ohms, or

$$\frac{30 \times \cdot 21 \times 22 \cdot 26}{100} = 1 \cdot 40,$$

making the calculated resistance at 90° = 23·66 ohms; and since the resistance of our tested wire actually was 26 ohms at 90°, the conductivity of the wire was—

$$26 : 23 \cdot 66 :: 100 : = 91 \text{ per cent.},$$

as compared with pure copper, instead of 85·6, as first stated.

The following table gives these relations still more accurately: as an example of its use, suppose a wire to give a resistance of 22·26, at 60° Fahrenheit, what will it give at 90°? or with a difference of 30 degrees:—

$$22{\cdot}26 \times 1{\cdot}065 = 23{\cdot}707.$$

TABLE for calculating the Resistance of Copper at different Temperatures.

To increase from lower Temperature to higher, multiply the Res. by the number in Column 2.				To reduce from higher Temperature to lower, multiply the Res. by the number in Column 4.			
No. of degrees.	Column 2.	No. of degrees.	Column 2.	No. of degrees.	Column 4.	No. of degrees.	Column 4.
0	1·			0	1·		
1	1·0021	16	1·0341	1	0·9979	16	0·9670
2	1·0042	17	1·0363	2	0·9958	17	0·9650
3	1·0063	18	1·0385	3	0·9937	18	0·9629
4	1·0084	19	1·0407	4	0·9916	19	0·9609
5	1·0105	20	1·0428	5	0·9896	20	0·9589
6	1·0127	21	1·0450	6	0·9875	21	0·9569
7	1·0148	22	1·0472	7	0·9854	22	0·9549
8	1·0169	23	1·0494	8	0·9834	23	0·9529
9	1·0191	24	1·0516	9	0·9813	24	0·9509
10	1·0212	25	1·0538	10	0·9792	25	0·9489
11	1·0233	26	1·0561	11	0·9772	26	0·9469
12	1·0255	27	1·0583	12	0·9751	27	0·9449
13	1·0276	28	1·0605	13	0·9731	28	0·9429
14	1·0298	29	1·0627	14	0·9711	29	0·9409
15	1·0320	30	1·0650	15	0·9690	30	0·9390

CHAPTER XIX.

To ascertain the Locality of Faults.

WHEN a line is broken down at any spot, one of four cases generally occurs :—

a. Either the line is broken, and makes full, or nearly full earth at the fault;

b. Or the line is unbroken, but makes a partial earth, nearly sufficient to make the signals imperceptible;

c. Or the fault is caused by two wires being in metallic contact, so that the signals sent on one wire are communicated to both;

d. Or the line is broken asunder without making contact with earth.

In all cases it is essential to record frequent measurements of the resistance of each circuit, so that when a fault occurs the *resistance per mile* may be known. If the broken line makes full earth, the resistance of the broken line, divided by the *resistance per mile*, gives the distance of the fault from the station; and if the distant station obtains a corresponding result the confirmation is

complete. Thus, in a line of one hundred miles in length, if the tests from the two extremities indicate distances of forty-five and fifty-five miles respectively, the locality is clearly indicated.

Usually, however, the fault gives a very considerable resistance where the line makes contact with earth, so that the sum of the two resistances greatly exceeds the resistance of the line itself when perfect. In such cases it is usual to estimate the fault midway between the two points indicated; thus if the respective resistances indicate eighty-six miles and twenty-six miles, the sum of these exceeds one hundred miles by twelve, and therefore half this excess, or six, is deducted from each of the measures. The same rule applies in testing submarine cables, and it is worthy of remembrance that the resistance at the fault will often make the distance appear five, ten, or even fifty or more miles farther off than it actually is; even in the largest faults in submarine cables, where the copper is fully exposed, it is prudent to allow from two to five miles for the resistance of the fault itself. The nearest approximation is obtained by first applying the positive current, which clothes the fault with an insoluble salt of copper, and increases the resistance enormously; the application of the negative current then dissolves the salt and rapidly reduces the resistance: at the moment when the copper is bright and clean, the resistance is at a minimum, and gives the truest approximation to the real resistance of the line: if the negative current be continued beyond this, hydrogen gas is formed, and the

resistance increases, and rises and falls capriciously as the bubbles of gas escape.

The author has pointed out that the resistance of a *small* fault is much greater with a small battery power, say five cells, than with a higher power, say fifty cells; but if the fault be a *large* one the resistance will be more nearly equal; and if a great length of copper be exposed the resistances will be the same: this fact affords a valuable means of obtaining the approximate resistance of a fault.

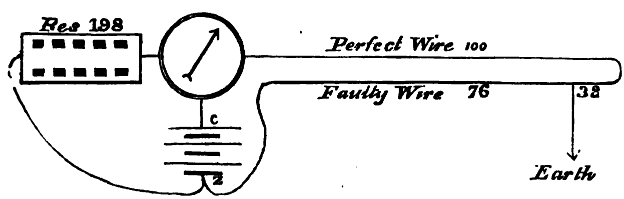
If the line is unbroken, but yet makes a partial earth at the fault sufficient to weaken signals, two or three methods present themselves. The first plan is that of direct measurement from both ends alternately, as given above, the distant end of the line being in each case insulated; in this case the resistance of the fault is measured twice over, and is roughly allowed for by the method of calculation above given.

CHAPTER XX.

The Method of taking the Loop Test.

THE second and more accurate plan is that known as the "loop test," which gives a measure entirely independent of the resistance of the fault. It can, however, only be employed when there are two or more parallel wires to the circuit. To make this test, first ascertain the resistance of the faulty wire (before it was injured) and that of any other perfect wire running parallel with it. This should be taken from previous records, but, if unknown, the sum of the two resistances may be obtained as follows :—

Fig. 23.

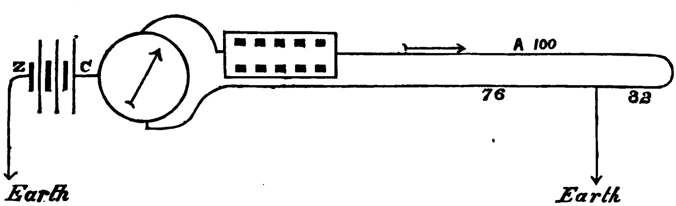


Plug in B and C, and attach one pole of the battery to

the "key" terminal. Have the two lines joined together at the distant station, and attach one of them to D and the other to the remaining pole of the battery. Connect also one end of the resistance coil to the same battery pole, and the other end to terminal A. When this is done, the connections will be as shown in fig. 23, and, on depressing the key and varying the resistance coil, the sum of the resistances of the two lines may be correctly ascertained. Although the fault makes earth at E, this will not affect the measurement, since there is no other earth connection in the circuit.

Having thus ascertained the resistance of the double line, alter the connections as follows: put one pole of the battery to earth and the other to the "key" terminal; plug in B and C; attach the perfect wire to the terminal D, and connect the faulty wire to the terminal A, interposing, however, a resistance coil in circuit between the terminal and the line. The connections will then be as shown in fig. 24:—

Fig. 24.



And on depressing the key, the battery current will flow into both lines simultaneously, passing to the earth at the

fault E, and by varying the resistance so as to bring the needle to zero, we shall make the sum of the resistance of the perfect wire A and the portion x, equal to the sum of the resistances of the other portion z and the coil R, or, $R + z = A + x$.

When this is the case, the position of the fault is at once determined, for we have only to add together all the resistances in circuit, viz., A, x, z and R, and one half the sum will indicate the position of the fault as measured from the instrument in either direction through A and x, or through R and z.

For example, let the resistance of the perfect line be one hundred, and of the injured line ninety-eight, and suppose the fault to be at thirty-two ohms from the distant station. Now, to obtain equilibrium of the needle, we shall require on one side of the instrument $100 + 32 = 132$, and on the resistance coil side of the instrument $56 + 76 = 132$, and the needle will remain at zero whatever be the resistance of the fault or however it may vary at different times. The sum of these four resistances is 264, and the half sum is 132, which, measured in either direction, indicates the position of the fault. If the resistance of both lines be equal, the resistance unplugged at the coil will be always twice the resistance of the fault measured from the distant station, or twice x.

CHAPTER XXI.

Blavier's Formula for finding the Position of a Fault.

WHERE there is only one line, and it has a fault in it, the following method may be resorted to with advantage, and it has the merit that it only requires an unskilled assistant at the other end of the line. Three tests have to be taken for the operation, viz. :—

Let R = the resistance of the line before it was defective (this must be obtained from previous records).

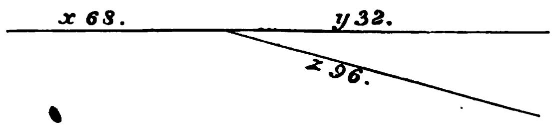
S = the resistance of the line when to earth at the distant end.

T = the resistance of the line when disconnected from earth at the distant end.

Having obtained these three resistances, multiply S by S, and T by R, and add the products together; subtract from this amount T times S, and also R times S. Whatever the remainder be, find its square root, and subtract it from the resistance S; the remainder will give the resistance x, or the distance of the fault from the station.

Although this process appears complicated, it is really very easy, and occupies but little time. For example: suppose the line to be one hundred units long, and the fault at sixty-eight units' distance, and suppose the resistance of the fault to be 96 units, as shown in fig. 25:—

Fig. 25.



then $R = x + y \quad = \quad 68 + 32 = 100$

$$S^{*} = x + \frac{y \times z}{y + z} = 68 + \frac{32 \times 96}{32 + 96} = 92$$

$$T = x + z = 68 + 96 = 164$$

We shall, however, have obtained these resistances by measurement, and not by calculation. We have therefore—

$$\left.\begin{array}{l} S \times S = 92 \times 92 = 8464 \\ T \times R = 164 \times 100 = 16400 \end{array}\right\} 24864$$

$$\left.\begin{array}{l} T \times S = 164 \times 92 = 15088 \\ R \times S = 100 \times 92 = 9200 \end{array}\right\} \begin{array}{r} 24288 \\ \hline 576 \end{array}$$

And the square root of 576 is 24,† which, deducted from

* See page 81.

† If the student is unacquainted with the proper method of extracting this, he may obtain it by trial and error: thus, 20 × 20, 30 × 30, 40 × 40, &c.

S (= 92), gives 68 as the resistance of x, or the distance of the fault from the station.

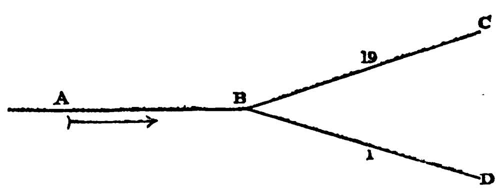
Of course, knowing this distance x, the others are obtained with ease; for $R-68$ gives y, or the distance from the opposite end, and $T-68$ gives z, or the resistance of the fault itself. This test should, where practicable, be taken from both ends of the line. In the above calculations the resistance of the fault is supposed to remain constant during the measurement of the resistances S and T; but as in practice this is very apt to vary, the average of several measurements should be taken.

CHAPTER XXII.

On Shunts and derived Circuits.

SHUNTS and derived circuits are of such constant occurrence in telegraphy, that it is necessary to understand well their properties. They occur in two forms which, although they at first sight appear different, are essentially the same. In fig. 26, a current flowing from

Fig. 26.



A towards C and D divides itself between B C and B D, and if these have an equal resistance, one half the current flows by each branch; if they are unequal in their resistance the rule is equally simple. Suppose

the resistances to be respectively 19 ohms and 1 ohm; then if we suppose the whole current to consist of 20 parts (19 + 1), then $\frac{19}{20}$ths will flow through the wire which has a resistance of 1 ohm, and $\frac{1}{20}$th through that which has 19 ohms; that is to say, *the quantities of electricity passing are inversely as the resistances:* the numbers, in fact, only require changing places to represent the quantities passing.

Fig. 27.

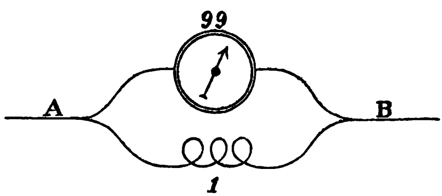


Fig. 27 shows another form of derived circuit, with a galvanometer included in one of the circuits, in fact, an ordinary shunt; and here the same rule applies: if the longer circuit, including the galvanometer, has a resistance of 99, and the shorter circuit, or shunt, of 1, then calling the whole quantity 100 (99 + 1), 99 parts of the current will pass through the shunt wire, and 1 only through the galvanometer.

CHAPTER XXIII.

On the multiplying Proportion of Shunts, and their Resistance.

THE preceding rule gives us at once the means of calculating the influence of shunts on a galvanometer; for if, out of 100 parts, only one goes through the galvanometer, it is evident that the influence on the galvanometer will be only $\frac{1}{100}$ part of what it would be if the whole current had passed through it—in common parlance, the shunt has a multiplying power of 100. The following is a convenient way of committing this to memory:—

$$\textit{The multiplying power of a shunt} = \frac{\text{galv.} + \text{shunt}}{\text{shunt}}.$$

$$\text{or } \frac{99 + 1}{1} = \frac{100}{1} = 100.$$

On the Resistance of divided or shunted Circuits.

We must now deal with the resistance of such a divided circuit (fig. 26 or 27), and here the rule is as follows.

Calling the resistance of one circuit R, and the other r, *the joint resistance of any two circuits* $= \frac{R \times r}{R + r}$, or *the resistance equals the product divided by the sum.* Thus, in fig. 26 we have resistance $= \frac{19 \times 1}{19 + 1} = \frac{19}{20} = \cdot 95$; and again, in fig. 27, we have res. $= \frac{99 \times 1}{99 + 1} = \frac{99}{100} = \cdot 99$, and in circuit of two resistances, each 10, we have $\frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5$; and this form of calculation refers equally to a divided circuit, as in fig. 26, or to a shunted circuit, as in fig. 27. If we wish to obtain the total resistance of the circuits we must of course add those of the lengths A and B. Sometimes three or more wires branch off from one spot, and in this case the same principles apply. First find the joint resistance of any two of the circuits, and considering this as one resistance, combine it with the remaining one, and so on. For example, let the resistances be 30, 60, and 80: we have first $\frac{30 \times 60}{30 + 60} = \frac{1800}{90} = 20$, and then $\frac{20 \times 80}{20 + 80} = \frac{1600}{100} = 16$.

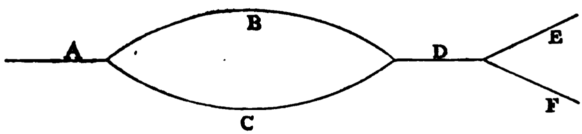
Another, and often a readier method of obtaining the joint resistance of two or many circuits is as follows: *add together their reciprocals, and the sum will be the re-*

*ciprocal of their joint resistance.** Thus, in the case above given, the resistance

$$= \frac{1}{\frac{1}{30} + \frac{1}{60} + \frac{1}{80}} = \frac{1}{\cdot 0333 + \cdot 0167 + \cdot 0125} = \frac{1}{\cdot 0625} = 16.$$

The *conducting power* of any circuits, whether simple or combined, is of course inversely as their resistances; that is, it varies as the reciprocals of their resistances. Fig. 28

Fig. 28.

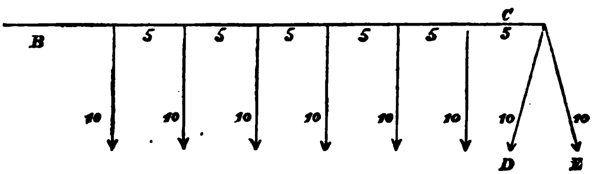


represents a compounded circuit of which the resistance would be thus calculated. First obtain the joint resistance of E and F, and add it to that of D. To this amount add the joint resistance of B and C, and finally that of A. For the sake of practice, the student may also with advantage calculate the resistance of the accompanying circuit, beginning with D and E, and then including C, and so on. The calculation is extremely easy, and he will soon perceive that he may elongate the figure to any extent in the direction of B, and

* The reciprocal of any number is obtained by dividing 1 by the number: thus $\frac{1}{30}$, or ·0333, is the reciprocal of 30, &c.

add any number of similar branches (each of which will convey a portion of the current to earth), without in the least degree changing the total resistance as measured from B.

Fig. 29.



He will also perceive the analogy which this case bears to that of an ordinary line circuit, where every pole conveys a certain quantity of electricity to the earth by reason of its imperfect insulation.

CHAPTER XXIV.

On Measurement by the Electrical Balance.

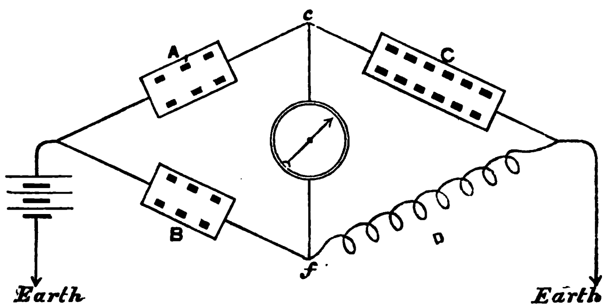
THIS arrangement — commonly known as the Wheatstone balance—is of extended use in telegraphy, and usually takes the place of the differential galvanometer; for very delicate measurements it is indeed a more sensitive and reliable instrument.

The arrangement is usually drawn in the form shown at fig. 30, in which the galvanometer is supposed to be connected up in the manner described at page 50.

In all cases it consists of four parts, A B C and D, with a galvanometer connected across at the junctions *c* and *f*. When a battery current is passed through the arrangement it divides itself into two circuits, one portion flowing through A and C, and the other portion through B and D; and if all four resistances be equal the current will have no tendency to pass across from *c* to *f*, and the galvanometer will remain at zero; but if they be of unequal resistance, then the current will flow from *c* to *f*, or *vice versâ*, and the galvanometer will be deflected.

Having then found two equal resistances A and B, and inserted some unknown wire at D, we have only to unplug the resistance coil at C until the galvanometer remains at zero, and the resistance unplugged gives an accurate measure of the resistance of D. When the

Fig. 30.



needle remains stationary the following relations always exist between the four parts: if A is equal to B, then C must be equal to D; or if A is equal to C, then B must be equal to D. The following is a more general expression of the proportions which must exist:—

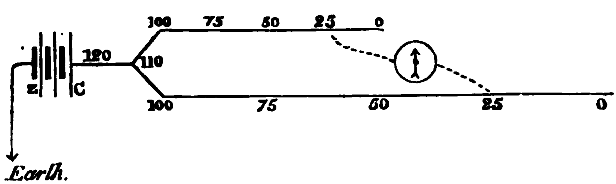
A : B : : C : D, and consequently,

A : C : : B : D

To understand clearly the nature of this arrangement, the student must remember that, in every case, the circuit is divided at some point into two branches, and therefore that at this point *the two tensions are equal.* At some

other point the two branches are again joined together, as in fig. 30, or else they both go to earth, as in figs. 31 and 32, and they are therefore at this point *again at equal tension*, whatever may be the lengths of the two circuits in the intervening space. Now calling the tension at the point where the branches first diverge 100, and at the point where they meet again (or where they are connected to earth) 0, let us divide each circuit into 100 equal spaces, as in fig. 31.

Fig. 31.

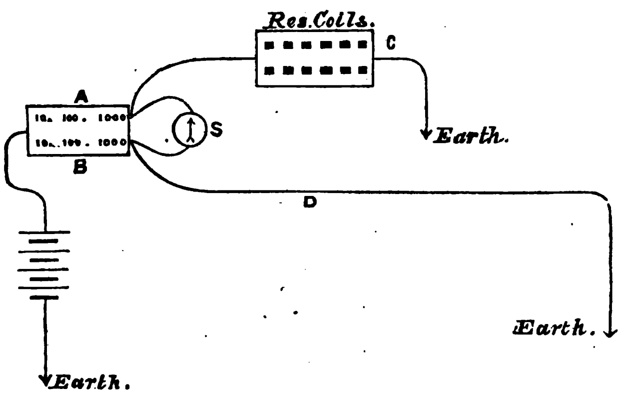


If now a wire be joined across from one half circuit to the other, connecting 50 to 50, or 75 to 75, or as shown in the drawing, 25 to 25, or between any other two points of equal tension, no current will flow through it, because the tensions at these points are similar; but if they are connected between any two points of *unequal* tension, as, for example, from 50 to 25, of course some current will flow through it, and the galvanometer will be deflected. The proportions above given, A : B : : C : D, which obtain when the tensions are equal, are therefore obvious enough: in the instance given it only amounts to our saying, 75 : 75 : : 25 to 25,

and similarly in all other cases; and the other proportion, A : C :: B : D, is in effect only to say, 75 : 25 :: 75 : 25.

It is very usual in practice to unite A and B in one box, as shown in fig. 32, having two parallel sets of resistances of ten, one hundred, and one thousand ohms, and by employing ten on one side, and one hundred or one thousand on the other, the corresponding resistances

Fig. 32.



on coil C will have to be multiplied or divided by ten or one hundred, in accordance with the proportions above given; of course, any other two known resistances may be employed at A and B. For example, suppose A to be 290 units, B 1500, and C 6420, then—

A : B :: C : D; or,

290 : 1500 :: 6420 = 33207 ohms.

CHAPTER XXV.

On the Measurement of Gutta-percha Cables.

THE measurement of the insulation of gutta-percha wire so often becomes necessary that a few remarks about its testing may be useful; the method of making the tests has already been given at pages 56 and 57*; its resistance, however, varies so greatly with its temperature, that without taking this into account very little idea can be formed of its degree of insulation. It is always customary to test it when manufactured at a temperature of 75° Fahr. (or 24° Centigrade), and to refer to its insulation at this temperature; its resistance at 32° is, however, more than fourteen times as great as it is at 75°. On the opposite page will be found a table giving its resistance at different temperatures, taking that at 75° as = 1.

Supposing then that we have measured the resistance of a length of 50 miles of cable, at a temperature of 40, and find it to be 70·4 megohms, the resistance of each mile would be $70{\cdot}4 \times 50 = 3520$ megohms. Referring to 40° in the table, we find 8·76, and if we wish to know its resistance per mile at the standard temperature, or 75°, we have the simple proportion—

$$8{\cdot}76 : 1 :: 3520 : 401{\cdot}8 \text{ megohms.}$$

* See also Appendix.

We have, in fact, only to *divide the resistance we obtain by the number in the table* corresponding to the temperature of the cable at which we obtained it.

To find the resistance at any other temperature, we have only a case of simple proportion. Suppose we have tested a cable giving 100 ohms at 45° Fahr., and wish to know its resistance at 60°; we have the following proportion :—

As the resistance given in the table for 45° (6·425) is to the resistance given at the required temperature (2·535), so is the actual resistance of our cable to its resistance at the required temperature, or—

6·425 : 2·535 : : 100 ohms : 39·45 ohms.

TABLE of the relative Resistance of Gutta-percha at different Temperatures.

Fahr.	Resistance.	Fahr.	Resistance.	Fahr.	Resistance.	Fahr.	Resistance.
90°	·394	75°	**1·000**	60°	2·535	45°	6·425
89	·420	74	1·064	59	2·697	44	6·835
88	·447	73	1·132	58	2·869	43	7·273
87	·475	72	1·204	57	3·053	42	7·738
86	·506	71	1·282	56	3·248	41	8·233
85	·538	70	1·364	55	3·456	40	8·760
84	·572	69	1·451	54	3·680	39	9·132
83	·609	68	1·543	53	3·912	38	9·917
82	·648	67	1·642	52	4·162	37	10·55
81	·689	66	1·747	51	4·429	36	11·22
80	·733	65	1·859	50	4·712	35	11·94
79	·780	64	1·978	49	5·013	34	12·71
78	·830	63	2·104	48	5·334	33	13·52
77	·883	62	2·239	47	5·675	32	14·38
76	·940	61	2·382	46	6·038		

APPENDIX.

PART I.—ELECTRICAL FORMULÆ.

OHM'S LAW.

$$Q = \frac{E}{R}$$

where Q = the quantity of the current, or the strength, or the force, or the intensity of the current, as it is variously called.

E the electromotive force.

R = the total resistance in circuit; or,

$$Q = \frac{n\,E}{n\,R + r}$$

where n represents the number of cells.

E = their electromotive force.

R = their internal resistance.

r = the resistances exterior to the battery.

CONDUCTING POWER.

Conduction is the converse of resistance. The reciprocal of any resistance represents its conductivity or conduction; or the conduction is obtained by dividing 1 by the resistance: thus, $\frac{1}{100}$, $\frac{1}{379}$.

The conducting power of any wire varies as $\frac{w}{l^2}$.

The joint conducting power of any two or more circuits having resistances = a, b, and c:

= reciprocal a + reciprocal b, etc.,

or as the sum of the reciprocals.

TABLE of the Relative Conductivity of different Metals at 32° Fahr.

Silver	100
Copper, pure	99·9
„ selected commercial	85 to 95
„ ordinary commercial	40 to 70
Brass	20
Gold	78
Zinc	29
Steel	about 16
Iron	about 15
German silver	12 to 16
Tin	12·4
Lead	8·3
Platinum	6·9
Mercury	1·6

TABLE giving the Resistance in Ohms of various Metals and Alloys at 32° Fahr.

(Jenkin: Cantor Lectures.)

NAME OF METALS.	Resistance in ohms of a wire one foot long, weighing one grain.	Resistance in ohms of a wire one foot long and one thousandth of an inch (one mil) in diameter.	Percentage in variation of resistance per degree of temperature Fahr.
Silver, hard drawn	·2421	10·787	·209
Silver, annealed	·2214	9·936	
Copper, annealed	·2064	9·718	·215
Gold	·5849	12·52	·202
Aluminium	·0682	17·72	
Zinc	·5710	38·22	·202
Platinum	3·536	55·09	
Iron	1·242	59·10	
Nickel	1·078	75·78	
Tin	1·317	80·36	·202
Lead	3·236	119·39	·215
Antimony	3·324	216·00	·216
Bismuth	5·054	719·0	·196
Mercury	18·740	600·0	·040
1 Silver, 2 Platinum*	4·243	148·35	·017
1 Silver, 2 Gold	2·391	66·10	·036
German silver	2·652	127·32	·024

* This alloy is used for making standard resistances.

MEASUREMENT OF CURRENTS.

1. **With a Thomson's reflecting galvanometer** the strength of the current or the quantity per second is

directly proportional to the angle of deflection: shunts may be used so as to bring the deflections within the range of the instrument.

2. **With an ordinary galvanometer** the deflection caused by the weaker current may be reproduced by inserting a shunt with the stronger current; the *shunt ratio* (page 80) will represent that of the currents; but it must not be forgotten that the resistance has been varied at the same time.

3. **With a sine galvanometer** the strength of the current is proportional to the *sine* of the angle of deflection. A table of sines is given at page 157.

4. **With a tangent galvanometer** the strength is proportioned to the *tangent* of the angle of deflection. A table of tangents is given at page 157.

5. **The method of vibrations** is sometimes a convenient one for determining the strength of the current or its quantity. Place the coils of a horizontal galvanometer, with a suspended needle, east and west, so that the needle is at right angles to it: the current will not, therefore, cause any deflection. Then set the needle vibrating, and count the number of vibrations in one minute, or any other period of time (under the influence of the earth's magnetism only), and call this m. Then

ascertain the number when the current c is passing, and lastly when the current C is passing.

Then m^2 represents the force of the earth's magnetism,
c^2-m^2 represents that of the current c,
C^2-m^2 that of the current C,
$\frac{C^2-m^2}{c^2-m^2}$ = the force of C in terms of c,

and $\frac{C^2-m^2}{m^2}$ = the force of C in terms of the earth's magnetic force.

It is necessary that the galvanometer should have but one needle, and that this should never swing outside the coils.

6. **By the Voltameter.**—In this instrument the quantity of the current is proportional to the quantity of gas formed.

7. **By the heating of a fine wire.**—The heat produced in any circuit is proportional to the square of the quantity of current passing.

MEASUREMENT OF RESISTANCES.

1. **By Wheatstone's Bridge.**—This method of measurement, and that by the differential galvanometer, are described at page 84, and at page 54 *et seq.*

2. **By addition to a known circuit.**—This method requires the use a Thomson's, or other galvanometer, whose deflections have a known value: if with a galvanometer, battery, and resistance coil, whose total resistance is R, we get a deflection D, and if after the addition of the unknown resistance x we get another deflection d, then—

$$d : D :: R : R + x,$$

$$\text{and } x = \frac{D \times R}{d} - R.$$

3. **By comparison with another resistance.**—It may occur that the operator have no resistance coils and only one known resistance. Let Z be the unknown resistance of the battery and galvanometer, including, if necessary, any other resistances. Let X be the resistance we wish to measure, and let R be a known resistance. Also, let D be the deflection with Z, d that with R + Z, and d' that with X + Z. We must first obtain the value of Z, from which we can afterwards obtain that of X.

$$\text{Now } D : d :: Z + R : Z,$$

$$\text{and } Z = \frac{d \times R}{D - d}.$$

$$\text{Again, } D : d' :: Z + X : Z,$$

$$\text{and } X = \frac{D\,Z - d'\,z}{d'}.$$

(See also No. 10).

4. **By tensions.**—Connect one pole of a battery to earth. Insert a resistance coil R between the battery and the resistance x to be measured, which must also have its other end connected to earth. Measure the tensions T and t on each side of the resistance coil (see fig. 39, p. 128), then

$$T : t :: R + x : x,$$

$$\text{and } x = \frac{t \times R}{T - t}.$$

5. **To test ordinary lengths of insulated wire** the most sensitive instruments are necessary. Thomson's galvanometers are always used, and the following method is generally employed :—

Determine the deflection of the instrument with 1 cell through 10 megohms (by using a shunt with a multiplying power of 1000 and a resistance of 10,000 ohms). Call this deflection D. Test the length of core with a very large number of cells, N; let the length in yards be L, and let the deflection obtained with N cells (without the shunt) be d.

$$\text{Res. per naut. mile} = \frac{D \times N \times L}{d \times 2029} \times 10 \text{ megohms.}$$

6. **To test longer lengths of cable** a similar method is employed: the deflection D is obtained with about 2 cells, with a shunt having a multiplying power S, and

10,000 ohms. The deflection on the cable is obtained with, say 200 cells, without shunt, and is called d; the length in nautical miles is called L, and the ratio of the two batteries B.

We have, therefore, the original resistance, 10,000 ohms, multiplied by the multiplying power of the shunt S, by the number of cells or ratio between the two batteries B (= 100), by the length L, and by the original deflection D, and we have to divide the product by the deflection of the cable itself, d; or,

$$\text{Res. per mile} = 10{,}000 \text{ ohms } \frac{S \times B \times L \times D}{d}.$$

The ratio of the batteries may be obtained more correctly by the method given at page 109, and the ratio thus obtained should be substituted for the value B, where accuracy is desired.

7. Calculating Resistance by the time of falling to Half-Tension (*Jenkin*).

The resistance R of any core may be calculated from the time of falling to any tension by the formula

$$R = \frac{\cdot 4343 \times t}{F \times \log. \frac{C}{c}} \text{ megohms.}$$

Where F is the electrostatic capacity of the cable in farads per mile (or any other length), and t the time in seconds of falling from any tension C to any lower tension c.

When the fall is from tension to half-tension this formula becomes as follows: unfortunately these measures are of little practical value as they are greatly influenced by electrification:

$$R = \frac{1{\cdot}443 \times t}{F} \text{ megohms.}$$

INTERNAL RESISTANCE OF BATTERIES.

8. **By the sine or tangent galvanometer.**—If a battery joined up in circuit with a sine galvanometer give a certain number of degrees deflection, and we add resistance until the (sine of the) deflection becomes half what it was, we are certain that the resistance is doubled, and, therefore, that the resistance added is equal to the original resistance. If we deduct, therefore, the resistance of galvanometer and connections from the *resistance added*, we obtain the resistance of the battery.

9. **By Sir William Thomson's method.**—Join up in a circuit the battery, a resistance coil R, and a galvanometer G, and note carefully the deflection; then introduce a second wire S between one pole of the battery and the other: this will of course weaken the influence of the battery current, and the deflection of the galvanometer will become lessened: now decrease the resistance of the resistance coil R until the deflection of the needle becomes as great as before, and call the new resistance r: then—

$$\text{Res. of battery} = S \times \frac{R - r}{r + G}.$$

10. **By Clark's method.**—For this method a thick wire differential, or a shunted differential galvanometer is required. Connect the battery in circuit through one half the galvanometer only, and note the deflection; then connect it through both halves of the galvanometer, and add resistance until the deflection is reduced to its first amount: the resistance added will then be equal to the internal resistance of the battery (see p. 60).

11. **By a galvanometer whose deflections are proportional.**—Let D be the deflection obtained with the battery in current with a galvanometer, and some resistance r; and d the reflection with some larger resistance R (the resistance of the galvanometer being included in R and r); and let x = the resistance of the battery.

$$\text{Then } D : d :: R + x : r + x,$$

$$\text{and } x = \frac{(d \times R) - (D \times r)}{D - d}.$$

In using this method any other resistance y may be included with x, and the formula becomes—

$$x + y = \frac{(d \times R) - (D \times r)}{D - d},$$

and by deducting x we get the value of y; or, if y be large in comparison with x, the latter may be neglected. By this method one resistance r may be compared with another, as in No. 3.

12. **Measuring resistances by tension.**—If a re-

sistance coil be joined in circuit with a battery, and so adjusted that the tension at the point of junction is just half the full tension of the battery, the resistance of the coil will be equal to that of the battery (see p. 20).

PARALLEL OR DERIVED CIRCUITS.

1. **The joint resistance of any two parallel or derived circuits** having resistance = a and b is equal to their product divided by their sum, or

$$R = \frac{a\,b}{a+b}.$$

2. **The joint resistance of any three circuits** a, b, and c, is

$$R = \frac{a\,b\,c}{ab + bc + a\,c}.$$

3. **The joint resistance of any number of resistances** is obtained by adding together their reciprocals; the result will be the reciprocal of their joint resistance: thus—

$$R = \frac{1}{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}}.$$

(The foregoing formulæ refer equally to derived circuits which, after separating, unite again, or to those which branch off in two or more distinct circuits to earth.)

GALVANOMETERS AND SHUNTS.

4. **The joint resistance of a galvanometer and shunt** is as above, $\frac{\text{Galv}^{\text{r}}. \times \text{shunt}}{\text{Galv}^{\text{r}}. + \text{shunt}}$.

5. **The multiplying power of any shunt** is equal to $\frac{\text{Galv}^{\text{r}}. + \text{shunt}}{\text{shunt}}$, or $\frac{\text{Galv}^{\text{r}}.}{\text{shunt}} + 1$.

6. **To prepare any given shunt.**—It is sometimes necessary to prepare a shunt having some definite multiplying power, as for instance 10, 100, etc.: if we call the resistance of the galvanometer G, and of the required shunt s, and let n be the multiplying ratio we require, then—

$$s = \frac{G}{n - 1}.$$

For example, if a galvanometer of 990 units required a 100 shunt, its resistance must be $\frac{990}{100 - 1} = \frac{990}{99} = 10.$

MEASURES OF RESISTANCE.

1·0456 **Siemen's units** = 1 ohm.

To convert Siemen's units into ohms, multiply by ·9564 (see also page 43).

1 **Varley's unit** = 25 ohms.

1 **megohm** = 1 million ohms.

1 **microhm** = 1 millionth part of an ohm (see p. 43).

MEASUREMENT OF ELECTROMOTIVE FORCE, AND TENSION.

ELECTROMOTIVE FORCE.

Until the Committee of the British Association issues standards of electromotive force, this measure can only be given in terms of the force of some other battery: its measurement may be obtained on two systems—either by the application of Ohm's law to a battery in action where the resistances are known; or, by allowing the battery to remain inactive, and measuring the tension: in which cases the tension is the same as the electromotive force, and the resistances in circuit need not be known. The first five of the following methods belong to the former system, and Poggendorff's method is a combination of both.

To compare the electromotive forces of two batteries.—1. Let their force be E and E′; join them up successively in circuit with the same galvanometer, and, by varying their resistance, cause them both to give the same deflection; their forces will then be in direct proportion to the *total* resistances in circuit in each case, or

$$E' = E \times \frac{R'}{R},$$

where R represents the resistance with E (including that of battery, galvanometer, and the variable resistance), and R′ with E′.

2. If the external resistances be made very large indeed in comparison with that of the cells themselves, their internal resistance may often in practice be neglected, and only those of the galvanometer and resistance coil taken into account.

3. **Where the electromotive forces differ greatly,** it is often necessary to employ a shunt to diminish the deflection of the galvanometer and bring it within range with the more powerful battery: calling their resistances g and s, their joint resistance will be $\frac{g \times s}{g + s}$, which must be employed in calculating the total resistance of R: the respective electromotive forces are then

$$E' = E \times \frac{R \times \frac{g + s}{s}}{R' + g}.$$

4. Where shunts are used in obtaining both the deflections, the formula becomes

$$E' = E \times \frac{R \times \frac{g + s}{s}}{R' \times \frac{g + s'}{s'}}.$$

In all these cases $\frac{g + s}{s}$ represents the "multiplying power of the shunt" described at page 80.

5. **When a Thomson's reflecting galvanometer is employed** (or any other in which the deflections have

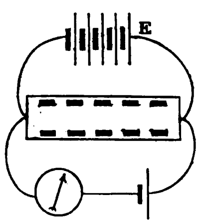
a known value), it becomes unnecessary to reproduce the same deflection: calling the deflections d and d', we have—

$$E' = E \times \frac{R \times d}{R' \times d'}.$$

6. **By the direct opposition of cells.**—Where a number of cells are joined up in circuit with, but in opposition to, a number of other cells with a galvanometer inserted, and the numbers adjusted so that no current passes, we have an obvious measure of their electromotive force.

7. **By Poggendorff's method.**

Fig. 33.



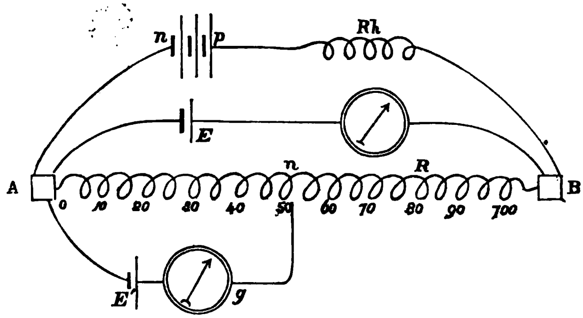
In this method the more powerful battery E is joined up in circuit with a resistance coil r, and the other battery E′ and a galvanometer are connected to the same coil, so that both batteries send a current through r in the same direction: by increasing the resistance of r it is easy either to make the current of E overpower that of E′, or to obtain such an equilibrium that E shall remain

inactive, and no current pass through the galvanometer in either direction. When this is effected, we have the following ratio: as the total resistance of E and *r* is to the resistance of *r*, so is the electromotive force of E to that of E′, or

$$E' = E \times \frac{r}{E + r}.$$

8. **By Clark's Potentiometer.**—It has been objected to the preceding system that, since one of the batteries is active, and the other not, we do not obtain a true comparison of the forces: although attaching little importance to this objection, the author has for many years past employed an instrument depending on similar principles, to which this consideration does not apply.

Fig. 34.



R is a coil of platinum wire of 100 turns, wound on an ebonite cylinder, which revolves on its axis like a Wheatstone's rheostat; the ends of the coil are connected

to the axles, which work in the blocks A and B; *p n* is a battery of several cells also connected to the blocks A and B, which sends a continuous current through R. A rheostat, *Rh.*, is also inserted, by which the total resistance of the circuit can be varied. E is a standard element (or a thermo-electric pile), also connected to the blocks A and B with an intervening galvanometer, which by a proper adjustment of the rheostat is just balanced by the battery *p n* in the manner before described, so that no current passes. Thus far the arrangement is similar to that of Poggendorff, except that E is used as the standard of comparison instead of *p n*. E′ is the cell whose tension or electromotive force we desire to measure, and this is connected with the block A and galvanometer *g*, and a moveable wire *n*, which can be applied to any part of the wire R.

Assuming the standard battery E to be exactly balanced by *p n*, and to have a tension of 100, and calling the tension at A = 0, we have between A and B every tension from 0 to 100; and by applying the wire *n* successively to different parts of the wire R we soon find a point where the tension of E is balanced, no current passing through *g*. A scale of equal parts measured along R gives the tension of the cell E′ by simple inspection.

By the use of a Thomson's galvanometer, and by fixing a divided scale on the revolving cylinder, it is easy to measure tensions accurately to the ten-thousandth or hundred-thousandth part of a Daniell's cell. When the battery E′ which we wish to measure is more powerful

than the standard battery E, their positions are reversed, and E is connected to the galvanometer *g*, and wire *n*. When this is the case, employing a scale of 100 parts, and calling *n* the number of divisions, we have

$$E' = E \times \frac{100}{n}.$$

TABLE giving Approximately the Electromotive Force of different Batteries.

Grove's.	100
Bunsen's	98
Daniell's	56
Smee's (when not in action)	57
Smee's (when in action) . . about	25
Copper and zinc in acid (Woollaston's) . .	46
Sulphate mercury and graphite (Marie Davy)	76
Chloride silver	62
Chloride lead	30

The foregoing determinations are the mean of a great many observations by the author, and give the electromotive force of the battery as taken on a sine galvanometer. When connected on short circuit, the electromotive force of several of the batteries, and especially the Smee's and Woollaston's, will fall off 50 per cent. or more, owing to the formation of hydrogen on the negative plate. Grove's and Daniell's do not so fall off, because the hydrogen is reduced by the nitric acid in the one case, and by the oxygen in the other. The internal resistance of Grove's cells is very small, usually below 1 ohm for a

pint cell; Daniell's, from 5 to 15 ohms (see page 60): Smee's, below 1 ohm, varying rapidly with the greater or less deposition of hydrogen.

The electromotive force of batteries is, within certain limits, very variable, depending on a variety of undetermined causes (see page 63). It is not much affected by temperature.

MEASUREMENT OF TENSION OR POTENTIAL.

9. **The potentiometer** last described is admirably suited for the measurement of potential, and has been used for tensions as high as 200 cells Daniell.*

10. **By the swing of the galvanometer needle.**—If a condenser of convenient capacity, or a short length of cable be immersed in water, and connected to a battery, and the charge be suddenly allowed to escape to earth through a galvanometer with a suspended needle, the swing of the needle will be nearly proportional to the quantity of electricity, and therefore proportional to the tension (the tension is more accurately equal to *the sine of half the angle of deflection*, but for a considerable range this does not differ sensibly from the angle).† By this method and the use of shunts *the tension of a whole battery may be obtained in terms of a standard cell.* Observe the

* See Government Report on the Construction of Submarine Cables, 1861, page 295.

† See p. 63. This method was first employed in England by the author in 1859; it appears also to have been used in Germany by Dr. Siemens about the same time. Its employment for the comparisons of batteries is due to Mr. Laws.

swing with the standard cell, and then shunt the galvanometer until the whole battery gives the same swing. Let T′ be the tension of the battery, and T that of the single cell; g and s the resistances of the galvanometer and shunt; then

$$T' = \frac{g+s}{s} \times T.$$

11. **If the arc of vibration be not equal,** and we call that of the battery d', and of the standard cell d, we have

$$T' = \frac{d'}{d} \times \frac{g+s}{s} \times T,$$

or, more correctly,

$$T' = \frac{\text{Sin}\ \frac{1}{2}\ d'}{\text{Sin}\ \frac{1}{2}\ d} \frac{(g+s)}{s} \times T.$$

12. **By opposing batteries.**—For measuring the tensions on a line, the method described at p. 18 is the most convenient. A secondary battery (fig. 10) is opposed to the main battery, and connected up in the same direction, with a galvanometer in circuit; the number of cells is varied until no current passes through the galvanometer, and this gives the tension of the line at that spot. If the balance cannot be obtained exactly, the addition of one more cell making the deflection too great, and its omission making it too small, the value of the fractional part of the cell is obtained by dividing either of the two opposite deflections by their sum. Thus, if with ten cells we get a deflection of three degrees on one side of zero,

and with eleven cells we get nine degrees on the other side, our real value is $10 + \frac{3}{3+9}$ cells, or $10\frac{3}{12}$ cells.

13. **By Thomson's slide resistance.**—This instrument is an arrangement of one hundred equal resistance bobbins, joined up in series, and having a resistance of one hundred ohms each, so that the whole slide has a total resistance of 10,000 ohms: metal blocks are fixed at the junction of each pair of bobbins, and these are arranged in a series, and numbered from one to one hundred, so that a sliding contact traversing the whole series can be made at pleasure with any bobbin in the set. One end of the series is connected to earth, and the other to a battery which sends a constant current through the whole series; the tensions at the metal blocks therefore fall regularly from the battery to the end connected to earth, where it is 0. Calling the tension at the battery end, whatever it may be, one hundred, we have every intermediate tension, at each successive block, from one hundred to one. Mr. Varley has, by means of a moveable derived circuit (reaching across two of the bobbins), which itself consists of one hundred coils, having each a resistance of twenty ohms, devised a means of subdividing each degree of tension into one hundred equal parts, so that the whole tension at the end next the battery is divided into 1000 equal parts. The use of this instrument in conjunction with an electrometer will be explained further on.

14. **By Thomson's electrometers.**—These are in-

struments in which the mechanical attraction and repulsion of electrified plates is used to indicate their difference of tension. They are made in two very distinct forms: the portable form, which will not indicate a smaller difference of tension than one Daniell's cell; and the *reflecting electrometer*, which is so beautifully sensitive that a hundredth part, or even a still smaller fraction of a Daniell's cell may be measured by it. The essential feature in each is the use of a moveable plane, which is kept *constantly electrified*, and is moved by attraction or repulsion. In the reflecting quadrant electrometer this electrified plane or needle is suspended over two pairs of conducting cheeks, which are provided with terminals on the exterior for making connections, and it inclines to one or the other of them according as their electrical charge is similar or opposite to its own. If both cheeks have the same tension the reflected spot of light remains at zero; but if one fall below the other, the needle is attracted, and the spot moves to one side or the other.

The resistance slide and the electrometer are generally used in conjunction; the cable, insulated at its further end, is connected with one pair of cheeks, and a loose wire is connected to the other pair. The cable is first charged from the battery end of the slide for some minutes, so that it acquires the tension of one hundred on the slide; it is then connected to the electrometer, the loose wire being shifted to the same tension, so that the electrometer remains at zero. As soon, however, as the cable is disconnected from the slide and battery, its

tension begins to fall, and the loose wire is gradually shifted down the scale, according to the indications of the electrometer; the *time of falling* from degree to degree being noted (see p. 117). In long cables, from their great electric capacity, the smallest change in the potential of the earth or of the battery produces so large a flow of electricity into or out of the cable that reliable measures can seldom be obtained by the galvanometer; the time of electrification has also a great influence on the result. The tension is not, however, sensibly influenced by these changes, and therefore in very long cables its measurement is the only one that can be relied upon.

15. **By adjusted condensers.**—If the electrometer above described were portable and not so costly, its use would become universal; for the time of falling from tension to half-tension being independent of all calculation, it would give from year to year the truest measure of the condition of any cable. As it is, however, unsuited for use in boats or on the sea-shore, the author has used condensers very successfully as a means of obtaining graduated tensions. If two condensers of known capacity, one (C) charged, and the other (c) empty, be united, and T be the tension of the battery, their joint tension t is readily found by the rule

$$t = T \times \frac{C}{C + c}.$$

If C and c be equal, their joint tension will be one-half the original tension. A condenser, therefore, is made in six parts, which, when successively united, give 90, 80, 70, 60, and 50 per cent. of the tension of the battery.

One of the condensers and the cable are charged for ten minutes from the same battery. The cable is allowed to remain insulated until its tension is supposed to have fallen to 90 per cent. of its original charge, and is then suddenly connected through a delicate galvanometer to the first pair of condensers. If the time has been correctly judged and the tension be 90, the galvanometer will be unaffected; if the tension be above or below 90, a minute charge will enter or leave the cable, deflecting the galvanometer to the right or left. Having thus obtained the time of falling to 90, 80, or 70 per cent., it is easy by the rule given at p. 117 to catch the precise moment of falling to 60 and 50. The charging of the condensers, their union, and subsequent connection through the galvanometer with the cable, are all effected by a single movement of a suitable key. The following are the capacities of the several parts of the condenser, which are such that A with B gives 90 per cent.; A with B and C 80 per cent., and so on:—

	Electrostatic capacity in farads.	
A (half the whole condenser)		·05
B	·00556	
C	·00694	
D	·00893	
E	·01190	
F	·01667	
		·05
		·100

16. **By Peltier's electrometer.**—This is a valuable instrument for laboratory experiments on short lengths

of cable, especially when combined with an electrophorus and a pair of equal condensers. The deflection with half the battery power is ascertained, and the time of falling to this deflection gives the insulation (see p. 98).

DEVELOPMENT OF HEAT AND WORK.

The quantity of heat developed in any electric circuit varies as the quantity of electricity passing in any given time and as the fall of tension. If E be the electromotive force of a battery, R the total resistance in circuit, and Q the quantity of electricity in farads, then $Q = \frac{E}{R}$, and the total heat developed $= \frac{E^2}{R}$.

Let $T - t$ represent the fall of tension or difference of potential at any two points in an electric circuit, then heat $= Q \times (T - t)$. If resistance R be taken into consideration, since $Q = \frac{T - t}{R}$, heat $= Q^2 \times R$.

If we take the difference of potential in volts V (p. 43), the quantity in farads F, the resistance in megohms M, and let H represent the heat which will raise a gramme (15·44 grains) of water one degree centigrade, then

$$H = V \times F \times 4157250, \text{ or } \frac{V^2 \times 4157250}{M}.$$

If W represent the equivalent of work done in grammes raised to the height of one metre,

$$W = V \times F \times 9808, \text{ or } \frac{V^2 \times 9808}{M}.$$

ELECTROSTATIC CAPACITY, CHARGE, AND DISCHARGE.

The electrostatic or inductive capacity of any cable, or other insulated body, is the charge which it will receive with the unit tension, or the volt.

The charge in a cable or condenser, or on any electrified body, varies directly as the tension; it also varies inversely as the distance between the inducing surfaces, and is generally considered to exist only on those surfaces, and not within the interior of a conducting body.*

The ratio of discharge, or the time required for the charge in any cable to fall to any given tension, does not vary with the degree of tension. If seven per cent. of the charge escape from any cable at 75° Fahr., during the first minute (and with gutta-percha this is about the usual quantity), seven per cent. *of the remaining quantity* will escape during the second minute, and so on *ad infinitum.* By continually subtracting seven per cent. from each re-

* The author considers it probable that the phenomena of *residuary discharge,* or absorption, or electrification, are due to the induction of layers of positive and negative electricity, which have penetrated partially into the substance of the dielectric from opposite sides, and are continually uniting and neutralizing each other. Each layer while *in transitu* behaving exactly as if it were on an interior surface of the dielectric, and inducing a similar amount of electricity on the opposite surface of the insulator—or within its substance.

mainder, we may easily ascertain the number of minutes required for falling to half or any other given tension; or,

Let C be the original charge in the cable, and c the observed charge at the end of the first minute; or at any other time, t. Let p be the amount of charge we wish to remain in the cable; then the time of falling to this tension will be $\dfrac{\log.\dfrac{C}{p}}{\log.\dfrac{C}{c}} \times t = n\,t.$

It usually happens that we want to know *the time of falling from charge to half-charge*, or, what is the same thing, from *tension to half-tension*. In this case $\log.\dfrac{C}{p} = \log.\dfrac{100}{50} = \cdot 30103$, and the formula becomes

$$\frac{\cdot 30103}{\log.\dfrac{C}{c}} \times t = n\,t.$$

The joint tension of two condensers or cables, when one is charged by another, is as follows:

Let C = capacity of the charged condenser,
and T = its tension;
and c = capacity of the other condenser,
and t = the tension when they are united.

$$\text{Then } T \times \frac{C}{C+c} = t.$$

THE JOINT ELECTROSTATIC CAPACITY OF TWO CABLES.

If a charged cable or condenser be joined to another cable, the charge will divide itself between the two in proportion to their respective capacities, the tension being the same in both. Let C be a standard condenser, charged to tension T, and let x be another condenser or cable, and t their joint tension when combined.

$$\text{Then } t : \text{T} :: \text{C} : \text{C} + x,$$

$$\text{and } \text{C T} = \text{C}\,t + x\,t.$$

$$\text{The capacity of } x \text{ will be, } x = \frac{\text{T} - t}{t}\,\text{C}.$$

To compare the inductive capacity of one cable with another, or with a condenser (Varley).

Ascertain which takes the greater charge, the cable or the condenser. If it be the cable, connect it to one coil of the differential galvanometer, and shunt that half of the galvanometer by resistance coils: connect the condenser to the other coil of the galvanometer: by depressing the key, take charge or discharge tests, varying the resistance of the shunt until the needle does not move.

Let s be the resistance of the shunt.

g, that of one coil of the galvanometer.

c, the length of cable represented by the condenser.

l, the length of the cable.

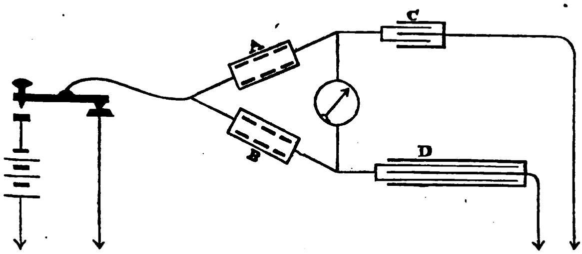
$$\text{Then } s : s + g :: c : l;$$

$$\text{and } l = \frac{g + s}{s} \times c.$$

√

By De Sauty's Method.—This plan is on the same principle as the Wheatstone balance.

Fig. 35.



The condensers C and D are attached in the manner shown in the figure, and the resistances A and B are so adjusted that, when the key is raised or depressed, no movement takes place in the needle: when this is the case,

$$A : B :: C : D;$$

$$\text{and } D = \frac{C\,B}{A}.$$

The electrostatic capacity of cables may be compared by the means of resistance coils and a galvanometer, without the use of any condenser (Jenkin). Determine by experiment the resistance R of the circuit through which the battery used to charge the cable would produce the unit deflection on the galvanometer used to measure the discharge. (The unit deflection is 90° on a sine galvanometer, 45° on a tangent, and one

division on a Thomson's reflecting galvanometer). Next count the number of oscillations which the galvanometer needle, when swinging freely, will make per minute, and let t equal the time occupied by half a complete oscillation of the needle, and let a be the angle to which the needle is thrown by the discharge; then the capacity—

$$C = 2 \frac{t \sin \frac{1}{2} a}{3 \cdot 1416 \ R}.$$

To obtain the relative inductive capacity of short lengths of cable.—Let D be the discharge from the condenser, and d that from the cable; L the length in yards, and 2029 the length of a mile; and let C be the constant of the condenser (if not exactly 1 mile), or the equivalent length of cable.

$$\text{Inductive capacity} = \frac{D \times 2029}{d \times L \times C}.$$

The inductive capacity of cables, where D = diameter of the dielectric, and d the diameter of the copper, varies directly as their length, and inversely as $\log. \frac{D}{d}$: if the length be constant,*

$$C = \frac{1}{\log. \frac{D}{d}}, \text{ or } C = \frac{1}{\log. D - \log. d};$$

and if the diameter of the conductor be constant,

$$C = \frac{1}{\log. D}.$$

* For the capacity in farads, see pp. 147, 151.

The charge, or inductive capacity of a strand conductor, is about five per cent. less than that of a solid conductor of the same diameter. The diameter of a 7-wire strand is three times that of one of the wires composing it.

RATE OF SIGNALLING.

The speed of working in any cable varies as log. $\frac{D}{d}$ multiplied by the square of the diameter of the conductor, or, what is the same thing, by the weight per mile of copper; it also varies inversely as the square of the length. Let D = diameter of the dielectric, and d that of the copper,

$$\text{Speed} = \frac{d^2 \times \log.\frac{D}{d}}{l^2}, \text{ or} = \frac{\text{weight of copper} \times \log.\frac{D}{d}}{l^2}.$$

If the length be constant it varies as $d^2 \times \log.\frac{D}{d}$; and if the size of the conductor be also constant the speed varies as log. D.*

If one cable have twice or thrice the diameter or size of another cable, and also twice or thrice its length, the speed of both will be the same.

The highest speed theoretically attainable is when the diameter of the conductor is to that of the dielectric as 1 to 1·649, or as ·6065 to 1: when this is the case, the

* See note *b*, p. 168.

copper weighs about 5·2 times as much as the gutta-percha, and log. $\frac{D}{d}$ becomes ·2172.

TABLE of Actual Working Speed on Several Cables.

Cable and Section.	Date of Experiment.	Length in Nautical Miles.	Total Resistance of Line, Ohms.	Log of $\frac{D}{d}$.	Actual No. of Words per Minute.
RED SEA.					
Suakin—Aden . . .	1860	629	..	..	11
MALTA AND ALEXANDRIA.					
Malta—Tripoli . . .	1861	230	802·	0·48089	·25
Tripoli—Benghazi . .	..	507	1769	..	·18
Benghazi—Alexandria .	..	597	2084	..	·15
Malta—Alexandria . .	..	1330	4641	..	3·2
PERSIAN GULF.					
Fao—Bushire	1864	155	1020	0·53839	25
Manora—Gwadur . .	..	266	1515	..	20
Gwadur—Mussendom .	..	358	2294	..	·16·7
Mussendom—Bushire .	..	329	2401	..	17·5
Mussendom—Fao . .	..	547	3420	..	12·1
Mussendom—Manora .	..	624	3785	..	9·64
ATLANTIC CABLE, 1865	1867	1896	7652	0·50200	17
Do. do. 1866	..	1857	7270	..	17

THE MEASUREMENT AND DETECTION OF FAULTS.

1. **To ascertain the position of a fault** by direct measurement.

This method is described at page 69.

2. **By Blavier's formula.** See page 75.

Let R be the resistance of the line when it was perfect, S the resistance of the faulty line when the distant end is to earth, and T the resistance when it is disconnected from earth.

The distance x of the fault from the station will be

$$x = S - \sqrt{S^2 + TR - TS - RS},$$

$$\text{or } x = S - \sqrt{(R - S) \times (T - S)};$$

and the resistance of the fault z will be

$$z = T - S + \sqrt{S^2 + TR - TS - RS},$$

$$\text{or } z = T - S + \sqrt{(R - S) \times (T - S)}.$$

3. **By Varley's loop test.** (See page 73.)

Let the resistance of the longer half of the loop be y.

That of the shorter half, x.

The total resistance of both, L.

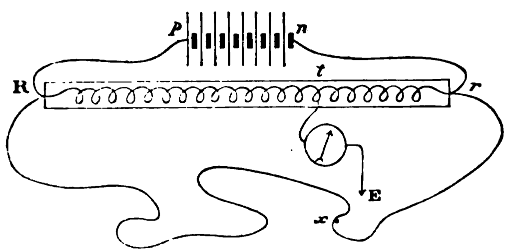
The resistance added to the shorter half to make it equal to the longer, R.

$$\text{Then } x + y = L,$$
$$y = x + R,$$
$$\text{and } x = \frac{L - R}{2}.$$

If we add together all the resistances in the circuit the fault will be at the midway point.

4. By Murray's test.

Fig. 36.



This test, like the preceding, requires a double line, so that both ends of the line may be in connection with the instrument. *p n* is a battery very carefully insulated from the earth, with its poles connected to the two extremities of a Thomson's slide R *r*. The two ends of the line are also connected to the slide, and *x* is the position of the fault; a constant current therefore flows through the slide from R to *r*, and also through the line from R through *x* to *r*. A galvanometer *g*, connected to the earth at E, is provided with a loose wire *t*, which is moved along the slide until some point is found at which no current passes through it, the tension being

equal to 0; when this point is found, if we call the two portions of the slide Rt and tr, and the two portions of the line Rx and xr, we have the following ratio between their resistances:

$$Rt : tr :: Rx : xr.$$

Calling the length of the whole line L, and the resistance of the slide 10,000, the distance of the fault x from the point R will be

$$Rx = \frac{Rt \times L}{10{,}000},$$

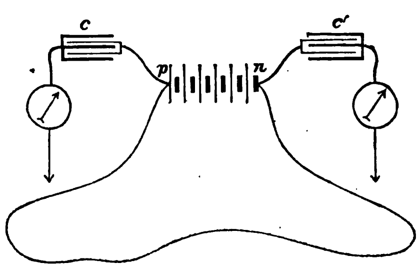
and the distance from r will be

$$rx = \frac{rt \times L}{10{,}000}.$$

Of course, where a slide is not available, ordinary resistance coils may be used for obtaining the resistances Rt and rt.

5. **By Clark's accumulation test.**—This method, which was first practised by the author upon a cable in the London Docks in 1860, is peculiarly suited for ascertaining the position of a very minute fault in an otherwise perfect cable during manufacture.

Fig. 37.



Both ends of the line are connected to a battery of a considerable number of cells, and the current flows continuously through it; two equal condensers, C and C′, are also connected to the opposite poles of the battery, with the usual provisions for measuring their respective charges; no connection is made with the earth anywhere, except through the fault x, and the whole system is allowed to remain quiescent for a considerable time.

However minute the fault x may be, it will, after some interval of time, reduce the potential of the line at that spot to 0; and when this is the case all the other tensions along the line, including those of the condensers and battery, will adjust themselves according to well-known laws: the tension of the condenser C will be positive, and that of C′ will be negative; and if the fault x were exactly in the centre of the line their charges would be equal in amount though opposite in sign; but if it be in any other point their charges will vary relatively in accordance with its position, and if we measure the discharge from the condensers C and C′ the following rule will obtain:

$$C : C' :: p\,x : n\,x.$$

Calling the length of the line L, the distance of x from the point p will be

$$p\,x = \frac{L \times C}{C + C'},$$

$$\text{and } n\,x = \frac{L \times C'}{C + C'}.$$

As one of the condensers gives a positive discharge

and the other a negative, it is necessary to use a reversing key to bring both deflections into the same direction, and it is obvious that the tensions at C and C′ may be measured by a Thomson's electrometer, instead of by condensers.

6. **Testing by Thomson's slide** (see p. 111).—This is in principle the same as Wheatstone's balance, the parts A and C, p. 85, being replaced by the two portions of the slide, whose total resistance is 10,000 units.

Fig. 38.

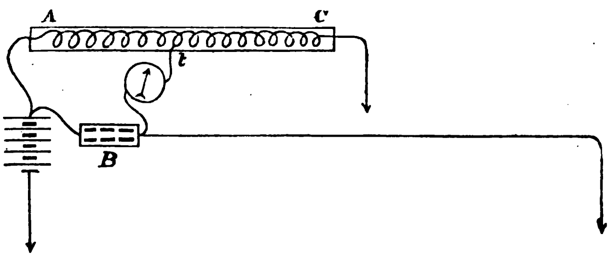


Fig. 38 is a diagram showing the arrangement of the parts.

A battery with one pole to the earth has the opposite pole connected through the slide A C to earth, so that a constant current passes through it; it is also connected through a resistance coil B to the line D, which is supposed to be connected to earth or to be faulty; a galvanometer is connected to B, and carries a loose wire *t*, which is moved along the slide A C until a point is found where no current passes through it: when this point is

found we have the same ratios as in the Wheatstone balance, viz.,

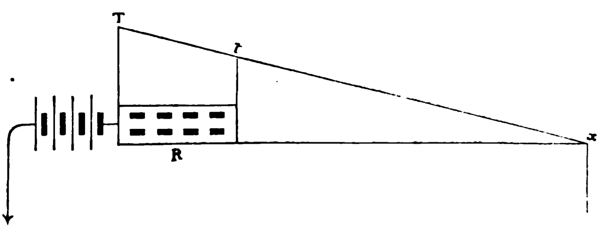
$$A : C :: B : D,$$

$$\text{also } A : B :: C : D,$$

$$\text{and } D = \frac{B \times C}{A}.$$

7. **Measuring resistances by tension.**—This is a very good way of ascertaining the resistance or the position of a fault in a line or cable. Instead of measuring the resistances directly, the tensions are measured at two different points, either by the discharge from a condenser, or by a Thomson's electrometer and slide, in the manner before described, and from their ratio the distance of the fault is determined.

Fig. 39.



Let the line L make full earth at the fault x, or at its further end, as the case may be. Let R be a resistance coil, and T and t the tensions at each end of the coil, and let x be the distance of the fault from R; then

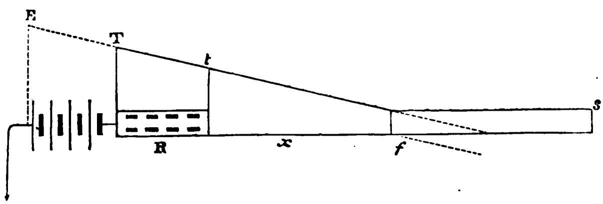
$$T - t : t :: R = x,$$

$$\text{and } x = \frac{t \times R}{T - t}.$$

It is sometimes better to vary the resistance R until the tension t be exactly half that of T. When this is the case we have x = R.

8. **When the fault makes a partial earth only.**—

Fig. 40.



Let b and R be a battery and resistance coil connected to a cable or line, $x f s$. Let f be the position of a fault, x the resistance of the line between the station or ship and the fault, and $f s$ the line beyond the fault, whose length is immaterial and need not be known. It is assumed that we have the means of correctly measuring the tensions at the points T, t, and s in common measure: if the line be perfect and in the act of paying out, this is easily obtained by insulating the end s; the tension of the line will then be everywhere equal to E, or the electromotive force of the battery, and this gives a standard measure both to ship and shore, which should be observed very frequently. If a fault afterwards appear on the line this tension at and beyond the fault will at once fall to some lower degree, as f or s, and these tensions will be equal whatever be the length of the line between f and s. Having then obtained the tension of

the line at f by measuring that at s, and having also measured the tensions at T and t, we have the following proportions:

$$T - t : t - s :: R : x.$$

Or, if we include the battery in our measures, calling its resistance b, we have

$$E - t : t - s :: b + R : x,$$

from whence we get the distance of the fault;

$$x = \frac{(t - s) \times R}{T - t},$$

$$\text{or } x = \frac{(t - s) \times (b + R)}{E - t},$$

and for the resistance of the line including that of the fault, we have

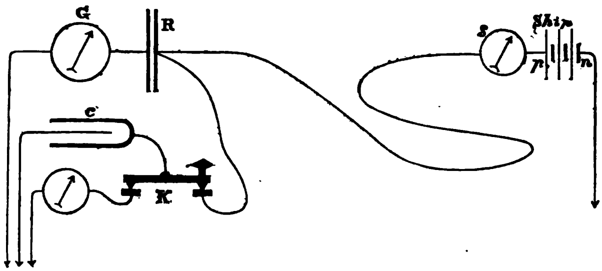
$$x + f = \frac{t \times R}{T - t},$$

from which, by deducting x, we obtain the value of f. During the laying of the Atlantic cables these tensions were recorded on shore every five minutes by the discharge of a condenser, and their value signalled through the cable to the ship.

9. **Willoughby Smith's system of testing cables** during submersion. This excellent system was first employed during the laying of the Atlantic cables in 1866. Either the ship or the shore becomes the controlling station, and fig. 41 gives the arrangement when the ship controls, as was the case on the occasion referred to.

G is a Thomson's galvanometer connected with the cable, and R is a very high resistance inserted in the circuit. This resistance may be made of gutta-percha,

Fig. 41.



selenium, or other imperfectly conducting material, and should have a resistance of 20 or 30 megohms. A battery of 100 cells is permanently connected to the cable on board ship, with an intervening galvanometer S, on which the state of insulation of the cable is constantly indicated. There is no battery on shore; but the galvanometer G, which is a highly sensitive one, maintains a steady deflection, due to the very feeble current which passes through the resistance R: this deflection is recorded every minute. The ship reverses its current every fifteen minutes, which being observed on G, serves for a continuity test for the shore. The resistance R being so great, and being constant, does not sensibly interfere with the correct measurement of the insulation of the cable on board ship, nor does it sensibly affect the tension of the line at R, which is practically 100, or the

same as it is close to the battery. In the event of a fault occurring anywhere in the line it would be instantly indicated on board on the galvanometer S, and the tension at R would also fall below 100. In order to detect accurately the position of the fault, great care is taken on shore to observe accurately the tension at R. This is done every five minutes by measuring the discharge from a condenser C; the key *k* puts this condenser into contact with the line for ten seconds and then discharges it suddenly through the galvanometer *g*, whose deflection indicates the tension, which is at once transmitted to the ship. Knowing this tension before and after the occurrence of a fault, the ship can accurately calculate its position by the system described at No. 8. Every hour a check measurement of this tension is also taken by the electrometer and slide.

The condenser C has a capacity of about ten farads, and since the line has a tension of about one hundred volts, when it is charged from the line every five minutes it abstracts about 1000 farads of electricity from the cable, which is at once made good again by the battery. The effect of this is momentarily visible on the ship's galvanometer S, and serves to show them that the continuity of the line is perfect without at all interfering with their insulation test.

Lastly, another and very important use is made of this condenser, or rather of an independent one having a capacity of about twenty farads, both on ship and shore. Imagine R to represent a condenser, and suppose the

ship by means of a similar one and a battery to send two or more successive impulses into the line; although the line is already charged to a tension of 100, and although no electricity actually enters or leaves the cable, these impulses will be transmitted like waves through the line, and will produce distinct and sudden deflections on the galvanometer G to the right and left. In this way, by making the left-hand deflections represent dots, and the right-hand dashes, a continual correspondence can be carried on through the line without interference with its insulation test.

10. **When the conductor of a cable is broken.**— In testing the core of a cable during its manufacture, it is usual to measure and record the capacity of each mile, and the part of the line in which it is placed: if then the conductor should become broken within the gutta-percha during submersion, these records enable the distance to be ascertained. If the average capacity per mile be n farads and the capacity of the broken section be N farads, the distance of the fraction will be $\frac{N}{n}$ miles. Such a case occurred during the laying of the Persian Gulf cable, at a distance of about 80 miles, and the position of the fault was indicated in this manner within a few hundred yards. The discharge from a condenser of known capacity was taken through a galvanometer, and the discharge from the 80 mile section was afterwards taken through the same galvanometer, with a variable

shunt, which was adjusted so as to reproduce the same deflection. Let C be the capacity of the condenser expressed in miles of the cable, g and s the resistances of the galvanometer and shunt, and x the distance of the fracture, then,

$$s : g + s :: c : x,$$

$$\text{and } x = C \times \frac{g + s}{s}.$$

The methods of Mr. Varley and Mr. De Sauty (pp. 118, 119), are also well adapted for obtaining this measurement.

Testing for faults in short lengths of wire.— Minute faults in short lengths of wire are readily found by connecting a powerful battery to one end of the wire and drawing it slowly through a basin of water insulated by suspension on gutta-percha cords. A Peltier or Milner electrometer is connected with the basin, and renders any leakage apparent. Even the most perfect wires give a visible leakage on the electrometer, and it is therefore necessary to make some imperfect connection with the basin by a piece of wood or a wet thread, sufficient to reduce the normal leakage of the wire to a moderate degree of deflection, and any change in this is at once apparent. If the fault be very large a galvanometer will suffice to indicate it. A coil of a mile of wire wound on a drum, and insulated, may be treated in this way on an insulated stand, and gradually unwound; the electrometer being connected to the drum, and also

a high resistance. As long as the fault is on the drum, the electrometer will be deflected, but as soon as it is unwound the deflection will fall.

Warren's method.—Mr. Warren, electrician to Mr. Hooper, employs a somewhat similar, but superior arrangement. The coil of wire is wound on to two separate drums, both insulated, and an electrometer is connected to each. A powerful battery is connected to the wire, and the induction and the leakage through the dielectric cause each of the electrometers to become deflected. Both drums are now discharged by touching them with the hand, and the electrometers fall to zero. The drum which has a defect on it soon, however, acquires its tension again, and the electrometer deflects, the other one remaining unaffected. More wire is then unwound, till the fault appears on the other drum. The outside of the wire between the drums must be wiped very dry, the other parts should be moist.

The accumulation joint test.—The author has introduced a method which is very suitable for measuring the insulation of joints or other very short lengths of core. The battery is connected with the conducting wire, and the length of core to be tested is immersed in an insulated suspended trough. A condenser is connected with the water of the trough, so that all the electricity which escapes from the joint or length of wire in a given time (usually one minute) is collected in the con-

denser. At the end of the minute the whole of this charge is suddenly discharged by a key through a galvanometer, the deflection of which indicates the quantity which has leaked through the joint in the given time. Joints are very generally tested by this plan, the leakage from 12 or 20 feet of perfect cable forming the standard of comparison. If the leakage from a joint exceeds this quantity it is considered faulty, and rejected.

APPENDIX.

PART II.—COEFFICIENTS AND TABLES.

IRON.

The specific gravity of bar iron is about 7·7. 1 cubic foot weighs 481·25 lbs.

The breaking weight of the commonest iron rod is about 20 to 25 tons per square inch section; the breaking weight of drawn wires is very much greater, increasing as the wire is finer up to 40 and 50 tons per square inch. Hard drawn wires are much stronger than annealed or rolled wire, and the strength varies greatly with quality; no general rule for strength can therefore be given.

The weights in the table at page 141 are calculated on the assumption that 1 cubic foot of iron weighs 481·25 lbs.

The weight of any iron wire per nautical mile is $\frac{d^2}{62{\cdot}59}$ lbs.

The weight of any iron wire per statute mile is $\frac{d^2}{72 \cdot 15}$ lbs.

The diameter of any iron wire weighing n lbs. per statute mile = $\sqrt{72 \cdot 15 \times n}$ mils.*

The diameter of any iron wire weighing n lbs. per nautical mile = $\sqrt{62 \cdot 59 \times n}$ mils.

The conductivity of ordinary galvanized iron wire compared with pure copper, 100, averages about 14, or about $\frac{1}{7}$th that of pure copper.

The resistance per statute mile of a galvanized iron wire is about $\frac{360000}{d^2}$ ohms at 60° Fahr.

The resistance of No. 8 iron wire is about 13·5 ohms per statute mile, and of No. 4 about 7·8 ohms.

The resistance of iron increases about ·35 per cent. for each degree Fahr.

The weight of iron per nautical mile in any submarine cable is approximately $\frac{d^2 n}{6806}$ cwts., where d = the diameter of the wire in mils,* and n the number of wires. (See table, p. 140.)

* The mil is the thousandth part of an inch. A circular mil is a circular area one thousandth of an inch in diameter; there are therefore one million circular mils in a circular inch. It is much more

The diameter of any submarine cable is as follows:—Let D = diameter of cable, d that of the wires composing it, n the number of wires; then—

$$D = d \times (1 + \text{cosecant } \frac{180^\circ}{n}),$$

$$\text{or, approximately, } D = \frac{d \times (n \times 3{\cdot}2)}{3{\cdot}14}.$$

See table of diameters.

TABLE of the External Diameter of Submarine Cables.

Sizes. B.W.G.	Diameter in Mils.	NUMBER OF WIRES. 9	10	12	14	16	18
00	380	1·491	1·607	1·848	2·089	2·328	2·568
0	340	1·334	1·440	1·654	1·869	2·084	2·298
1	300	1·177	1·271	1·459	1·649	1·838	2·028
2	284	1·114	1·203	1·381	1 561	1·740	1·919
3	259	1·017	1·097	1·260	1·424	1·587	1·751
4	238	0·934	1·008	1·157	1·308	1·458	1·608
5	220	0·863	0·932	1·070	1·209	1·348	1·487
6	203	0·796	0·860	0·987	1·116	1·243	1·372
7	180	0·706	0·762	0·875	0·989	1·103	1·217
8	165	0·647	0·699	0·802	0·907	1·010	1·115
9	148	0·581	0·627	0·720	0·813	0·907	1·000
10	134	0·526	0·567	0·653	0·736	0·821	0·906
11	120	0·471	0·508	0·584	0·660	0·735	0·811
12	109	0·428	0·462	0·530	0·599	0·668	0·737
13	95	0·373	0·402	0·462	0·522	0·582	0·642
14	83	0·326	0·352	0·403	0·456	0·508	0·561
15	72	0·282	0·305	0·350	0·396	0·441	0·487
16	65	0·255	0·275	0·316	c·357	c·398	0·439
$1 + \text{cosecant } \frac{180}{n}$		3·9238	4·2360	4·8637	5·4964	6·1258	6·7588

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convenient in every way to speak of whole numbers than of decimals, and the author has therefore adopted the word mil (as recommended by Mr. J. Cocker) to express the thousandth part of an inch.

TABLE of the Weight of Iron per Nautical Mile in Cables of different Sizes.

INCLUDING 3 PER CENT. FOR LAY.

Size of Wire. B. W. G	Diameter in Mils.	NUMBER OF WIRES IN CABLE.					
		9	10	12	14	16	18
		cwts.	cwts.	cwts.	cwts.	cwts.	cwts.
00	380	190·87	212·08	254·49	296·91	339·32	381·74
0	340	152·68	169·64	203·57	237·50	271·42	305·35
1	300	118·84	132·05	158·45	184·86	211·27	237·68
2	284	106·51	118·35	142·02	165·68	189·25	213·02
3	259	88·53	98·36	118·04	137·71	157·38	177·06
4	238	74·72	83·02	99·62	116·22	132·83	149·43
5	220	63·96	71·07	85·28	99·50	113·71	127·93
6	203	54·32	60·36	72·43	84·50	96·57	108·64
7	180	42·73	47·48	56·98	66·48	75·97	85·47
8	165	35·78	39·76	47·71	55·66	63·61	71·56
9	148	28·92	32·14	38·56	44·99	51·42	57·84
10	134	23·64	26·26	31·52	36·77	42·02	47·28
11	120	19·00	21·11	25·34	29·56	33·78	38·01
12	109	15·57	17·30	20·76	24·22	27·69	31·15
13	95	11·86	13·18	15·82	18·46	21·09	23·73
14	83	9·08	10·09	12·11	14·13	16·15	18·17
15	72	6·77	7·52	9·02	10·53	12·03	13·53
16	65	5·47	6·08	7·29	8·51	9·72	10·94

TABLE of the Sizes and Weights of Iron Wire.

B. W. Gauge.	Diam. in Mils.*	Per Statute Mile. Weight in lbs.	Weight in cwts.	Resistance in ohms.	Nautical Mile. Weight in cwts.	Breaking Weight at 20 Tons per sq. ins.
						Cwts.
1 sq. in.	—	17645	157·54	·340	181·63	400
1 circ. in.	1000	13858	123·73	·433	142·65	314·16
0000	454	2854	25·48	2·10	29·38	64·40
000	425	2502	22·33	2·40	25·75	56·40
00	380	2001	17·86	3·00	20·59	45·36
0	340	1600	14·28	3·74	16·47	36·31
1	300	1245	11·12	4·81	12·82	28·27
2	284	1117	9·97	5·37	11·49	25·33
3	259	928	8·28	6·46	9·55	20·07
4	238	783	6·99	7·65	8·06	17·79
5	220	670	5·98	8·96	6·90	15·20
6	203	570	5·09	10·52	5·86	12·94
7	180	448	4·00	13·38	4·61	10·17
8	165	376	3·35	16·39	3·86	8·55
9	148	303	2·71	19·79	3·12	6·88
10	134	249	2·22	24·14	2·55	5·64
11	120	199	1·78	30·10	2·05	4·52
12	109	164	1·46	36·49	1·68	3·73
13	95	124	1·11	48·01	1·28	2·83
14	83	95	·85	62·93	·98	2·16
15	72	72	·64	83·65	·73	1·62
16	65	58	·52	102·6	·59	1·32
17	58	46·58	..	..	..	..
18	49	33·17	..	..	..	..
19	42	24·35	..	..	..	..
20	35	17·93	..	..	..	..
21	32	14·11	..	..	..	..
22	28	10·76	..	..	..	..

* See foot-note, p. 138.

COPPER.

The specific gravity of copper wire according to the best authorities is about 8·8.

One cubic foot of copper weighs 550 lbs.

The ordinary breaking weight of copper wire is about 17 tons per square inch, varying, however, greatly according to the size and temper.

The weight per nautical mile of any copper wire is about $\frac{d^2}{55}$ lbs., or more correctly (54·76), where *a* is the diameter in mils (thousandths of an inch), and 55 is a constant.

The weight per nautical mile of a copper strand is about $\frac{d^2}{70{\cdot}4}$ lbs.

The weight per statute mile of any copper wire is $\frac{d^2}{63{\cdot}13}$ lbs. A mile of No. 16 wire weighs in practice from 63 to 66 lbs.

The diameter of any copper wire weighing *n* lbs per nautical mile is $\sqrt{n \times 54{\cdot}76}$ mils.

The diameter of any copper wire weighing *n* lbs. per statute mile is $\sqrt{n \times 63}$ mils.

The diameter of a copper strand weighing n lbs. per nautical mile is about $\sqrt{n \times 70{\cdot}4}$ mils.

The diameter of any copper wire is half the square root of $\frac{w}{l}$, where w is the weight in ounces, and l the length, and d the diameter in inches.

The resistance of a nautical mile of pure copper weighing 1 lb. is—

at 32° Fahr. 1091·22 ohms
at 60° Fahr. 1155·48 „
at 75° Fahr. 1192·33 „ (See page 64.)

The resistance per nautical mile of any pure copper wire or strand weighing n lbs. is $\frac{1155{\cdot}48}{n}$ at 60° Fahr.

The resistance per nautical mile of any pure copper wire d mils in diameter is $\frac{63281}{d^2}$ ohms at 60° Fahr.

The resistance per nautical mile of any pure copper is $\frac{81361}{d^2}$ ohms at 60° Fahr.

The resistance per statute mile of any pure copper wire is $\frac{54892}{d^2}$ ohms, at 60° Fahr.

The resistance of a statute mile of pure copper weighing 1 lb. is 1002·4 ohms at 60 Fahr. No. 16 copper wire of good quality has a resistance of about 19 ohms.

The resistance of a statute mile of pure copper weighing n lbs. is $\frac{1002 \cdot 4}{n}$ ohms at 60° Fahr.

The resistance of any pure copper wire l inches in length, weighing n grains $= \frac{\cdot 001516 \times l^2}{n}$ ohms.

The resistance of copper increases as the temperature rises ·21 per cent. for each degree Fahr., or about ·38 per cent. for each degree Centigrade. A table of resistances at different temperatures is given below.

The conductivity of any copper wire is obtained by multiplying its calculated resistance by 100, and dividing the product by its actual resistance. Pure copper is taken as = 100. (See page 64.)

The conductivity of any copper wire, l inches in length, weighing w grains $= \frac{\cdot 1516 \times l^2}{w \times \text{res. in ohms}}$.

The conductivity of any copper may be determined by taking a standard having a resistance equal to 100 inches pure copper, weighing 100 grains at 60° Fahr. (= 0·1516 ohms). The conductivity of any other wire of similar resistance will be as the square of its length in inches, divided by its weight in grains.

TABLE for Calculating the Resistance of Copper at different Temperatures.

To increase from lower Temperature to higher, multiply the Res. by the number in Column 2.		To reduce from higher Temperature to lower, multiply the Res. by the number in Column 4.	
No. of Degrees.	Column 2.	No. of Degrees.	Column 4.
0	1·	0	1·
1	1·0021	1	0·9979
2	1·0042	2	0·9958
3	1·0063	3	0·9937
4	1·0084	4	0·9916
5	1·0105	5	0·9896
6	1·0127	6	0·9875
7	1·0148	7	0·9854
8	1·0169	8	0·9834
9	1·0191	9	0·9813
10	1·0212	10	0·9792
11	1·0233	11	0·9772
12	1·0255	12	0·9751
13	1·0276	13	0·9731
14	1·0298	14	0·9711
15	1·0320	15	0·9690
16	1·0341	16	0·9670
17	1·0363	17	0·9650
18	1·0385	18	0·9629
19	1·0407	19	0·9609
20	1·0428	20	0·9589
21	1·0450	21	0·9569
22	1·0472	22	0·9549
23	1·0494	23	0·9529
24	1·0516	24	0·9509
25	1·0538	25	0·9489
26	1·0561	26	0·9469
27	1·0583	27	0·9449
28	1·0605	28	0·9429
29	1·0627	29	0·9409
30	1·0650	30	0·9390

GUTTA-PERCHA AND INDIA-RUBBER.

The specific gravity of gutta-percha is about ·981.
1 cubic foot weighs 61·32 lbs.
1 nautical mile by 1 circular inch weighs 2036 lbs.
1 statute mile by one circular inch weighs 1765 lbs.

Unstretched gutta-percha begins to elongate permanently at a strain of 6 cwt. per square inch.

The following are a few of the standard sizes of gutta-percha wire in ordinary use :—

No.	Diameter in Mils.*	Weight of Percha per statute Mile.
		lbs.
0	143	36
8	161	46
7	171	52
6	194	66
5	214	81
4	221	86
3	247	108
2	276	134
1	289	147
0	340	204

The weight of gutta-percha per nautical mile is 1 lb. for each 481 circular mils of sectional area ; or for a solid cylinder $\frac{d^2}{481}$ lbs.

* See foot-note, page 138.

The weight of gutta-percha per nautical mile in any core is $\frac{D^2 - d^2}{481}$ lbs., where d is the diameter of the copper in mils, and D the diameter of the gutta-percha.

The weight of gutta-percha per statute mile $= \frac{D^2 - d^2}{554 \cdot 5}$.

The exterior diameter of any gutta-percha core $= \sqrt{n \times 70 \cdot 4 + N \times 481}$, where n is the weight in lbs. per nautical mile of copper strand, and N the weight of percha. With a solid conductor the diam. $= \sqrt{n \times 55 + N \times 481}$.

The electrostatic capacity per nautical mile of any gutta-percha core is approximately $\frac{\cdot 18769}{\text{Log.} \frac{D}{d}}$ farads. (See page 33.)

The electrostatic capacity of gutta-percha cores as compared with india-rubber cores of similar size is about as 120 to 100.

The resistance per nautical mile of a gutta-percha core of the best quality $= \frac{\text{Log.} \frac{D}{d}}{13}$ megohms at 75° Fahr.,

regarding the four left-hand figures of the logarithm as integer numbers, and the rest as decimals. (See page 34.)

The resistance of gutta-percha under pressure increases, according to Siemens, in the following ratio :—

Let R be the resistance and p the pressure in lbs. per square inch ; the resistance under pressure = R × (1 + ·00023 p).

The resistance of gutta-percha at 75° Fahr., as compared with Hooper's india-rubber compound, averages about as 100 to 1600.

The specific inductive capacity of gutta-percha is 4·2, that of Hooper's material 3·1, pure rubber 2·8 ; that of air being 1 (Jenkin).

The resistance of gutta-percha diminishes as the temperature increases ; the rate of increase is about as follows. Let R = resistance at the higher temperature ; r, resistance at the lower temperature ; t, the difference of temperature in degrees Fahr. : then—

$$\log. \text{ of } R = \log. \text{ of } r - t \log. \text{ of } {\cdot}9399$$

$$\text{and, } \log. \text{ of } r = \log. \text{ of } R + t \log. \text{ of } {\cdot}9399.$$

A table of resistance of gutta-percha at different temperatures is given in page 149.

TABLE of the relative Resistance of Gutta-percha at different Temperatures.

Fahr.	Resistance.	Fahr.	Resistance.
32°	14·38	62°	2·239
33	13·52	63	2·104
34	12·71	64	1·978
35	11·94	65	1·859
36	11·22	66	1·747
37	10·55	67	1·642
38	9·917	68	1·543
39	9·132	69	1·451
40	8·760	70	1·364
41	8·233	71	1·282
42	7·738	72	1·204
43	7·273	73	1·132
44	6·835	74	1·064
45	6·425	**75**	**1·00**
46	6·038	76	·940
47	5·675	77	·883
48	5·334	78	·830
49	5·013	79	·780
50	4·712	80	·733
51	4·429	81	·689
52	4·162	82	·648
53	3·912	83	·609
54	3·680	84	·572
55	3·456	85	·538
56	3·248	86	·506
57	3·053	87	·475
58	2·869	88	·447
59	2·697	89	·420
60	2·535	90	·394
61	2·382		

The ratio of resistance for each degree Fahr. is given in the above table, taking that at the standard temperature of 75° Fahr. as 1. To reduce any resistance from any temperature to 75°, multiply it by the corresponding number in the table. For reduction to other temperatures, the case must be treated as one of simple proportion. (See page 89.)

HOOPER'S MATERIAL.

The weight of Hooper's india-rubber compound per nautical mile is 1 lb. for every 401 circular mils of sectional area.

The weight of Hooper's compound per nautical mile in any cable is about $\frac{D^2 - d^2}{401}$ lbs.

The weight of Hooper's compound per statute mile $= \frac{D^2 - d^2}{462 \cdot 3}$.

The exterior diameter of any core of Hooper's compound is $= \sqrt{n \times 70 \cdot 4 + N \times 401}$, where N is the weight in lbs. per knot of the compound, and n of the copper strand.

The resistance per nautical mile of any core of Hooper's compound is about Log. $\frac{D}{d} \times 1 \cdot 5$ megohms at

75 Fahr., regarding the first four figures of the logarithm as whole numbers.

The electrostatic capacity per nautical mile of any core of Hooper's material is approximately

$$\frac{\cdot 14854}{\text{Log.}\frac{D}{d}} \text{ farads.}$$

SEA-WATER.

The specific gravity of sea-water is ordinarily 1·028.

One cubic foot weighs 64·24 lbs.

One cubic foot of distilled water weighs 62·5 lbs.

The pressure of the ocean is equal to 2·676 lbs. per square inch per fathom, or 1 ton 1 cwt. per statute mile.

The temperature of the ocean below a depth of 1200 fathoms is believed to be everywhere about 40° Fahr.

ENGLISH MEASURES OF LENGTH.

The nautical mile, or knot, is the same as the geographical mile; its length is variously given by different authorities; it is $\frac{1}{60}$th of a degree of latitude, but, owing to the configuration of the earth, this distance varies from 362,750 feet at the equator to 366,300 feet at

the poles. At the mean latitude of 45° it is $\frac{364540}{60}$ = 6075·7 feet; but in the latitude of Greenwich it is about 6083·3 feet. The measure of 6087 feet, or 2029 yards, is, however, in such general use that we prefer to retain it.

One nautical mile is about 2029 yards, or 6087 feet, or about $\frac{1}{8}$th more than a statute mile.

One statute mile is 1760 yards, or 5280 feet.

To convert nautical into statute miles, multiply by 1·153, or, as a rough approximation, add $\frac{1}{8}$th.

To convert statute into nautical miles, multiply by ·8674, or, as a rough approximation, subtract $\frac{1}{7}$th.

To convert square inches into circular inches, multiply by ·7854.

FRENCH AND ENGLISH MEASURES.

To convert metres into inches, multiply by 39·37.

To convert metres into feet, multiply by 3·281.

To convert metres into yards, multiply by 1·094.

Note.—For the purpose of memory, a metre may be considered as *three feet, three inches, and a third.*

To convert kilometres into statute miles, multiply by ·6214.

To convert kilometres into nautical miles, multiply by ·539.

To convert millimetres into inches, multiply by ·03937.

To convert grammes into grains, multiply by 15·44.

To convert kilogrammes into pounds, multiply by 2·205.

MEASURES OF TEMPERATURE.

The centigrade thermometer has the difference of temperature between freezing and boiling water divided into 100 degrees, these temperatures being respectively called 0° and 100°. They correspond to 32° and 212° on Fahrenheit's thermometer. 180° Fahr. are therefore equal to 100 cent., or the centigrade degrees are larger than Fahrenheit's, in the proportion of 18 to 10, or 9 to 5.

To convert centigrade temperatures above freezing into Fahrenheit, multiply them by 1·8, and add 32; or,

multiply by 2, subtract a tenth, and add 32.

Thus, 20 cent. $\times$ 2 = 40, and 40 − 4 + 32 = 68° Fahr.

The foregoing rule should be committed to memory as it is easily performed mentally.

The specific gravity of a cable or other body may be obtained by ascertaining its weight in air, W, and its weight in water. w: then

$$W - w : W :: 1 : \text{sp. gr.},$$

$$\text{and specific gravity} = \frac{W}{W - w}.$$

If a cable weigh n cwts. per mile, and have a specific gravity s, its weight in sea-water will be

$$n - \frac{n}{s} \times \cdot 973 \text{ cwts.}$$

STRAIN OF SUSPENDED WIRES.

The ordinary dip of line wires for a span of 80 yards is about 18 inches in mild weather: this gives with No. 8 wire a strain of 420 lbs.; its breaking weight being about 1300 lbs.*

The strain varies directly as the weight of the wire, and inversely as the dip or versine; it increases as the square of the span if the dip be constant, but to preserve a given strain the dip or versine must increase as the square of the span, or

$$L^2 : l^2 :: V : v.$$

The strain is greater at the point of suspension than at the lowest point of the span, by a quantity (equal to the weight of a length of wire of the same height as the versine) which may be neglected in practice. Calling

* Culley: *Handbook of Telegraphy.*

l the length of span in feet, w the weight in cwts. of one statute mile, v the versine in inches, and s the strain in lbs.—

$$\text{Strain} = \frac{l^2 \times w}{31 \cdot 43 \times v} \text{ lbs. approximately,}$$

$$\text{and dip} = \frac{l^2 \times w}{31 \cdot 43 \times s} \text{ inches.}$$

TABLE of the Birmingham Wire Gauge.

According to Holtzapffel.

B. W. Gauge.	Diam. in ins.	Sect. area in sq. ins.	B. W. Gauge.	Diam. in ins.	Sect. area in sq. ins.
1 circ. in.	1·000	·7854	17	·058	·00264
0000	·454	·16188	18	·049	·00188
000	·425	·14186	19	·042	·00138
00	·380	·11341	20	·035	·00096
0	·340	·09079	21	·032	·00080
1	·300	·07068	22	·028	·00061
2	·284	·06335	23	·025	·00049
3	·259	·05268	24	·022	·00038
4	·238	·04449	25	·020	·00031
5	·220	·03801	26	·018	·00025
6	·203	·03236	27	·016	·00020
7	·180	·02545	28	·014	·00015
8	·165	·02138	29	·013	·00013
9	·148	·01720	30	·012	·00011
10	·134	·01410	31	·010	·000078
11	·120	·01131	32	·009	·000063
12	·109	·00933	33	·008	·000050
13	·095	·00708	34	·007	·000038
14	·083	·00541	35	·005	·000019
15	·072	·00407	36	·004	·000012
16	·065	·00332			

TABLE of Natural Sines and Tangents.

Degrees.	Sine.	Tang.	Degrees.	Sine.	Tang.
1	·017	·017	46	·719	1·03
2	·035	·035	47	·731	1·07
3	·052	·052	48	·743	1·11
4	·070	·070	49	·755	1·15
5	·087	·087	50	·766	1·19
6	·104	·105	51	·777	1·23
7	·122	·123	52	·788	1·28
8	·139	·140	53	·798	1·33
9	·156	·158	54	·809	1·37
10	·173	·176	55	·819	1·43
11	·191	·194	56	·829	1·48
12	·208	·212	57	·838	1·54
13	·225	·231	58	·848	1·60
14	·242	·249	59	·857	1·66
15	·259	·268	60	·866	1·73
16	·275	·287	61	·874	1·80
17	·292	·306	62	·883	1·88
18	·309	·325	63	·891	1·96
19	·325	·344	64	·899	2·05
20	·342	·364	65	·906	2·14
21	·358	·384	66	·913	2·24
22	·374	·404	67	·920	2·35
23	·391	·424	68	·927	2·47
24	·407	·445	69	·933	2·60
25	·422	·466	70	·939	2·75
26	·438	·488	71	·945	2·90
27	·454	·509	72	·951	3·08
28	·469	·532	73	·956	3·27
29	·485	·554	74	·961	3·49
30	·500	·577	75	·966	3·73
31	·515	·601	76	·970	4·01
32	·530	·625	77	·974	4·33
33	·544	·649	78	·978	4·70
34	·559	·674	79	·981	5·14
35	·573	·700	80	·985	5·67
36	·588	·726	81	·987	6·31
37	·602	·753	82	·990	7·11
38	·615	·781	83	·992	8·14
39	·629	·810	84	·994	9·51
40	·643	·839	85	·996	11·43
41	·656	·869	86	·997	14·30
42	·669	·900	87	·998	19·08
43	·682	·932	88	·999	28·63
44	·694	·965	89	·999	57·29
45	·707	1·000	90	1·000	Infinite.

TABLE OF SQUARES OF DIAMETERS.

For finding the value of d^2 and $\sqrt{d}$.

Num.	Square.	Num.	Square.	Num.	Square.	Num.	Square.
1	1	38	1444	75	5625	112	12544
2	4	39	1521	76	5776	113	12769
3	9	40	1600	77	5929	114	12996
4	16	41	1681	78	6084	115	13225
5	25	42	1764	79	6241	116	13456
6	36	43	1849	80	6400	117	13689
7	49	44	1936	81	6561	118	13924
8	64	45	2025	82	6724	119	14161
9	81	46	2116	83	6889	120	14400
10	100	47	2209	84	7056	121	14641
11	121	48	2304	85	7225	122	14884
12	144	49	2401	86	7396	123	15129
13	169	50	2500	87	7569	124	15376
14	196	51	2601	88	7744	125	15625
15	225	52	2704	89	7921	126	15876
16	256	53	2809	90	8100	127	16129
17	289	54	2916	91	8281	128	16384
18	324	55	3025	92	8464	129	16641
19	361	56	3136	93	8649	130	16900
20	400	57	3249	94	8836	131	17161
21	441	58	3364	95	9025	132	17424
22	484	59	3481	96	9216	133	17689
23	529	60	3600	97	9409	134	17956
24	576	61	3721	98	9604	135	18225
25	625	62	3844	99	9801	136	18496
26	676	63	3969	100	10000	137	18769
27	729	64	4096	101	10201	138	19044
28	784	65	4225	102	10404	139	19321
29	841	66	4356	103	10609	140	19600
30	900	67	4489	104	10816	141	19881
31	961	68	4624	105	11025	142	20164
32	1024	69	4761	106	11236	143	20449
33	1089	70	4900	107	11449	144	20736
34	1156	71	5041	108	11664	145	21025
35	1225	72	5184	109	11881	146	21316
36	1296	73	5329	110	12100	147	21609
37	1369	74	5476	111	12321	148	21904

Table of Squares of Diameters—*continued.*

Num.	Square.	Num.	Square.	Num.	Square.	Num.	Square.
149	22201	193	37249	237	56169	281	78961
150	22500	194	37636	238	56644	282	79524
151	22801	195	38025	239	57121	283	80089
152	23104	196	38416	240	57600	284	80656
153	23409	197	38809	241	58081	285	81225
154	23716	198	39204	242	58564	286	81796
155	24025	199	39601	243	59049	287	82369
156	24336	200	40000	244	59536	288	82944
157	24649	201	40401	245	60025	289	83521
158	24964	202	40804	246	60516	290	84100
159	25281	203	41209	247	61009	291	84681
160	25600	204	41616	248	61504	292	85264
161	25921	205	42025	249	62001	293	85849
162	26244	206	42436	250	62500	294	86436
163	26569	207	42849	251	63001	295	87025
164	26896	208	43264	252	63504	296	87616
165	27225	209	43681	253	64009	297	88209
166	27556	210	44100	254	64516	298	88804
167	27889	211	44521	255	65025	299	89401
168	28224	212	44944	256	65536	300	90000
169	28561	213	45369	257	66049	301	90601
170	28900	214	45796	258	66564	302	91204
171	29241	215	46225	259	67081	303	91809
172	29584	216	46656	260	67600	304	92416
173	29929	217	47089	261	68121	305	93025
174	30276	218	47524	262	68644	306	93636
175	30625	219	47961	263	69169	307	94249
176	30976	220	48400	264	69696	308	94864
177	31329	221	48841	265	70225	309	95481
178	31684	222	49284	266	70756	310	96100
179	32041	223	49729	267	71289	311	96721
180	32400	224	50176	268	71824	312	97344
181	32761	225	50625	269	72361	313	97969
182	33124	226	51076	270	72900	314	98596
183	33489	227	51529	271	73441	315	99225
184	33856	228	51984	272	73984	316	99856
185	34225	229	52441	273	74529	317	100489
186	34596	230	52900	274	75076	318	101124
187	34969	231	53361	275	75625	319	101761
188	35344	232	53824	276	76176	320	102400
189	35721	233	54289	277	76729	321	103041
190	36100	234	54756	278	77284	322	103684
191	36481	235	55225	279	77841	323	104329
192	36864	236	55696	280	78400	324	104976

Table of Squares of Diameters—*continued.*

Num.	Square.	Num.	Square.	Num.	Square.	Num.	Square.
325	105625	369	136161	413	170569	457	208849
326	106276	370	136900	414	171396	458	209764
327	106929	371	137641	415	172225	459	210681
328	107584	372	138384	416	173056	460	211600
329	108241	373	139129	417	173889	461	212521
330	108900	374	139876	418	174724	462	213444
331	109561	375	140625	419	175561	463	214369
332	110224	376	141376	420	176400	464	215296
333	110889	377	142129	421	177241	465	216225
334	111556	378	142884	422	178084	466	217156
335	112225	379	143641	423	178929	467	218089
336	112896	380	144400	424	179776	468	219024
337	113569	381	145161	425	180625	469	219961
338	114244	382	145924	426	181476	470	220900
339	114921	383	146689	427	182329	471	221841
340	115600	384	147456	428	183184	472	222784
341	116281	385	148225	429	184041	473	223729
342	116964	386	148996	430	184900	474	224676
343	117649	387	149769	431	185761	475	225625
344	118336	388	150544	432	186624	476	226576
345	119025	389	151321	433	187489	477	227529
346	119716	390	152100	434	188356	478	228484
347	120409	391	152881	435	189225	479	229441
348	121104	392	153664	436	190096	480	230400
349	121801	393	154449	437	190969	481	231361
350	122500	394	155236	438	191844	482	232324
351	123201	395	156025	439	192721	483	233289
352	123904	396	156816	440	193600	484	234256
353	124609	397	157609	441	194481	485	235225
354	125316	398	158404	442	195364	486	236196
355	126025	399	159201	443	196249	487	237169
356	126736	400	160000	444	197136	488	238144
357	127449	401	160801	445	198025	489	239121
358	128164	402	161604	446	198916	490	240100
359	128881	403	162409	447	199809	491	241081
360	129600	404	163216	448	200704	492	242064
361	130321	405	164025	449	201601	493	243049
362	131044	406	164836	450	202500	494	244036
363	131769	407	165649	451	203401	495	245025
364	132496	408	166464	452	204304	496	246016
365	133225	409	167281	453	205209	497	247009
366	133956	410	168100	454	206116	498	248004
367	134689	411	168921	455	207025	499	249001
368	135424	412	169744	456	207936	500	250000

TABLE OF LOGARITHMS.

Num.	Log.	Num.	Log.	Num.	Log.	Num.	Log.
0	−∞	36	·55630	72	·85733	108	·03342
1	·00000	37	·56820	73	·86332	109	·03743
2	·30103	38	·57978	74	·86923	110	·04139
3	·47712	39	·59106	75	·87506	111	·04532
4	·60206	40	·60206	76	·88081	112	·04922
5	·69897	41	·61278	77	·88649	113	·05308
6	·77815	42	·62325	78	·89209	114	·05690
7	·84510	43	·63347	79	·89763	115	·06070
8	·90309	44	·64345	80	·90309	116	·06446
9	·95424	45	·65321	81	·90849	117	·06819
10	·00000	46	·66276	82	·91381	118	·07188
11	·04139	47	·67210	83	·91908	119	·07555
12	·07918	48	·68124	84	·92428	120	·07918
13	·11394	49	·69020	85	·92942	121	·08279
14	·14613	50	·69897	86	·93450	122	·08636
15	·17609	51	·70757	87	·93952	123	·08991
16	·20412	52	·71600	88	·94448	124	·09342
17	·23045	53	·72428	89	·94939	125	·09691
18	·25527	54	·73239	90	·95424	126	·10037
19	·27875	55	·74036	91	·95904	127	·10380
20	·30103	56	·74819	92	·96379	128	·10721
21	·32222	57	·75587	93	·96848	129	·11059
22	·34242	58	·76343	94	·97313	130	·11394
23	·36173	59	·77085	95	·97772	131	·11727
24	·38021	60	·77815	96	·98227	132	·12057
25	·39794	61	·78533	97	·98677	133	·12385
26	·41497	62	·79239	98	·99123	134	·12710
27	·43136	63	·79934	99	·99564	135	·13033
28	·44716	64	·80618	100	·00000	136	·13354
29	·46240	65	·81291	101	·00432	137	·13672
30	·47712	66	·81954	102	·00860	138	·13988
31	·49136	67	·82607	103	·01284	139	·14301
32	·50515	68	·83251	104	·01703	140	·14613
33	·51851	69	·83885	105	·02119	141	·14922
34	·53148	70	·84510	106	·02531	142	·15229
35	·54407	71	·85126	107	·02938	143	·15534

Table of Logarithms—*continued.*

Num.	Log.	Num.	Log.	Num.	Log.	Num.	Log.
144	·15836	180	·25527	216	·33445	252	·40140
145	·16137	181	·25768	217	·33646	253	·40312
146	·16435	182	·26007	218	·33846	254	·40483
147	·16732	183	·26245	219	·34044	255	·40654
148	·17026	184	·26482	220	·34242	256	·40824
149	·17319	185	·26717	221	·34439	257	·40993
150	·17609	186	·26951	222	·34635	258	·41162
151	·17898	187	·27184	223	·34830	259	·41330
152	·18184	188	·27416	224	·35025	260	·41497
153	·18469	189	·27646	225	·35218	261	·41664
154	·18752	190	·27875	226	·35411	262	·41830
155	·19033	191	·28103	227	·35603	263	·41996
156	·19312	192	·28330	228	·35793	264	·42160
157	·19590	193	·28556	229	·35984	265	·42325
158	·19866	194	·28780	230	·36173	266	·42488
159	·20140	195	·29003	231	·36361	267	·42651
160	·20412	196	·29226	232	·36549	268	·42813
161	·20683	197	·29447	233	·36736	269	·42975
162	·20952	198	·29667	234	·36922	270	·43136
163	·21219	199	·29885	235	·37107	271	·43297
164	·21484	200	·30103	236	·37291	272	·43457
165	·21748	201	·30320	237	·37475	273	·43616
166	·22011	202	·30535	238	·37658	274	·43775
167	·22272	203	·30750	239	·37840	275	·43933
168	·22531	204	·30963	240	·38021	276	·44091
169	·22789	205	·31175	241	·38202	277	·44248
170	·23045	206	·31387	242	·38382	278	·44404
171	·23300	207	·31597	243	·38561	279	·44560
172	·23553	208	·31806	244	·38739	280	·44716
173	·23805	209	·32015	245	·38917	281	·44871
174	·24055	210	.32222	246	·39094	282	·45025
175	·24304	211	·32428	247	·39270	283	·45179
176	·24551	212	·32634	248	·39445	284	·45332
177	·24797	213	·32838	249	·39620	285	·45484
178	·25042	214	·33041	250	·39794	286	·45637
179	·25285	215	·33244	251	·39967	287	·45788

Table of Logarithms—*continued.*

Num.	Log.	Num.	Log.	Num.	Log.	Num.	Log.
288	·45939	324	·51055	360	·55630	396	·59770
289	·46090	325	·51188	361	·55751	397	·59879
290	·46240	326	·51322	362	·55871	398	·59988
291	·46389	327	·51455	363	·55991	399	·60097
292	·46538	328	·51587	364	·56110	400	·60206
293	·46687	329	·51720	365	·56229	401	·60314
294	·46835	330	·51851	366	·56348	402	·60423
295	·46982	331	·51983	367	·56467	403	·60531
296	·47129	332	·52114	368	·56585	404	·60638
297	·47276	333	·52244	369	·56703	405	·60746
298	·47422	334	·52375	370	·56820	406	·60853
299	·47567	335	·52504	371	·56937	407	·60959
300	·47712	336	·52634	372	·57054	408	·61066
301	·47857	337	·52763	373	·57171	409	·61172
302	·48001	338	·52892	374	·57287	410	·61278
303	·48144	339	·53020	375	·57403	411	·61384
304	·48287	340	·53148	376	·57519	412	·61490
305	·48430	341	·53275	377	·57634	413	·61595
306	·48572	342	·53403	378	·57749	414	·61700
307	·48714	343	·53529	379	·57864	415	·61805
308	·48855	344	·53656	380	·57978	416	·61909
309	·48996	345	·53782	381	·58092	417	·62014
310	·49136	346	·53908	382	·58206	418	·62118
311	·49276	347	·54033	383	·58320	419	·62221
312	·49415	348	·54158	384	·58433	420	·62325
313	·49554	349	·54283	385	·58546	421	·62428
314	·49693	350	·54407	386	·58659	422	·62531
315	·49831	351	·54531	387	·58771	423	·62634
316	·49969	352	·54654	388	·58883	424	·62737
317	·50106	353	·54777	389	·58995	425	·62839
318	·50243	354	·54900	390	·59106	426	·62941
319	·50379	355	·55023	391	·59218	427	·63043
320	·50515	356	·55145	392	·59329	428	·63144
321	·50651	357	·55267	393	·59439	429	·63246
322	·50786	358	·55388	394	·59550	430	·63347
323	·50920	359	·55509	395	·59660	431	·63448

Table of Logarithms—*continued.*

Num.	Log.	Num.	Log.	Num.	Log.	Num.	Log.
432	·63548	468	·67025	504	·70243	540	·73239
433	·63649	469	·67117	505	·70329	541	·73320
434	·63749	470	·67210	506	·70415	542	·73400
435	·63849	471	·67302	507	·70501	543	·73480
436	·63949	472	·67394	508	·70586	544	·73560
437	·64048	473	·67486	509	·70672	545	·73640
438	·64147	474	·67578	510	·70757	546	·73719
439	·64246	475	·67669	511	·70842	547	·73799
440	·64345	476	·67761	512	·70927	548	·73878
441	·64444	477	·67852	513	·71012	549	·73957
442	·64542	478	·67943	514	·71096	550	·74036
443	·64640	479	·68034	515	·71181	551	·74115
444	·64738	480	·68124	516	·71265	552	·74194
445	·64836	481	·68215	517	·71349	553	·74273
446	·64933	482	·68305	518	·71433	554	·74351
447	·65031	483	·68395	519	·71517	555	·74429
448	·65128	484	·68485	520	·71600	556	·74507
449	·65225	485	·68574	521	·71684	557	·74586
450	·65321	486	·68664	522	·71767	558	·74663
451	·65418	487	·68753	523	·71850	559	·74741
452	·65514	488	·68842	524	·71933	560	·74819
453	·65610	489	·68931	525	·72016	561	·74896
454	·65706	490	·69020	526	·72099	562	·74974
455	·65801	491	·69108	527	·72181	563	·75051
456	·65896	492	·69197	528	·72263	564	·75128
457	·65992	493	·69285	529	·72346	565	·75205
458	·66087	494	·69373	530	·72428	566	·75282
459	·66181	495	·69461	531	·72509	567	·75358
460	·66276	496	·69548	532	·72591	568	·75435
461	·66370	497	·69636	533	·72673	569	·75511
462	·66464	498	·69723	534	·72754	570	·75587
463	·66558	499	·69810	535	·72835	571	·75664
464	·66652	500	·69897	536	·72916	572	·75740
465	·66745	501	·69984	537	·72997	573	·75815
466	·66839	502	·70070	538	·73078	574	·75891
467	·66932	503	·70157	539	·73159	575	·75967

Table of Logarithms—*continued.*

Num.	Log.	Num.	Log.	Num.	Log.	Num.	Log.
576	·76042	612	·78675	648	·81158	684	·83506
577	·76118	613	·78746	649	·81224	685	·83569
578	·76193	614	·78817	650	·81291	686	·83632
579	·76268	615	·78888	651	·81358	687	·83696
580	·76343	616	·78958	652	·81425	688	·83759
581	·76418	617	·79029	653	·81491	689	·83822
582	·76492	618	·79099	654	·81558	690	·83885
583	·76567	619	·79169	655	·81624	691	·83948
584	·76641	620	·79239	656	·81690	692	·84011
585	·76716	621	·79309	657	·81757	693	·84073
586	·76790	622	·79379	658	·81823	694	·84136
587	·76864	623	·79449	659	·81889	695	·84198
588	·76938	624	·79518	660	·81954	696	·84261
589	·77012	625	·79588	661	·82020	697	·84323
590	·77085	626	·79657	662	·82086	698	·84386
591	·77159	627	·79727	663	·82151	699	·84448
592	·77232	628	·79796	664	·82217	700	·84510
593	·77305	629	·79865	665	·82282	701	·84572
594	·77379	630	·79934	666	·82347	702	·84634
595	·77452	631	·80003	667	·82413	703	·84696
596	·77525	632	·80072	668	·82478	704	·84757
597	·77597	633	·80140	669	·82543	705	·84819
598	·77670	634	·80209	670	·82607	706	·84880
599	·77743	635	·80277	671	·82672	707	·84942
600	·77815	636	·80346	672	·82737	708	·85003
601	·77887	637	·80414	673	·82802	709	·85065
602	·77960	638	·80482	674	·82866	710	·85126
603	·78032	639	·80550	675	·82930	711	·85187
604	·78104	640	·80618	676	·82995	712	·85248
605	·78176	641	·80686	677	·83059	713	·85309
606	·78247	642	·80754	678	·83123	714	·85370
607	·78319	643	·80821	679	·83187	715	·85431
608	·78390	644	·80889	680	·83251	716	·85491
609	·78462	645	·80956	681	·83315	717	·85552
610	·78533	646	·81023	682	·83378	718	·85612
611	·78604	647	·81090	683	·83442	719	·85673

Table of Logarithms—*continued.*

Num.	Log.	Num.	Log.	Num.	Log.	Num.	Log.
720	·85733	756	·87852	792	·89873	828	·91803
721	·85794	757	·87910	793	·89927	829	·91855
722	·85854	758	·87967	794	·89982	830	·91908
723	·85914	759	·88024	795	·90037	831	·91960
724	·85974	760	·88081	796	·90091	832	·92012
725	·86034	761	·88138	797	·90146	833	·92065
726	·86094	762	·88195	798	·90200	834	·92117
727	·86153	763	·88252	799	·90255	835	·92169
728	·86213	764	·88309	800	·90309	836	·92221
729	·86273	765	·88366	801	·90363	837	·92273
730	·86332	766	·88423	802	·90417	838	·92324
731	·86392	767	·88480	803	·90472	839	·92376
732	·86451	768	·88536	804	·90526	840	·92428
733	·86510	769	·88593	805	·90580	841	·92480
734	·86570	770	·88649	806	·90634	842	·92531
735	·86629	771	·88705	807	·90687	843	·92583
736	·86688	772	·88762	808	90741	844	·92634
737	·86747	773	·88818	809	·90795	845	·92686
738	·86806	774	·88874	810	·90849	846	·92737
739	·86864	775	·88930	811	·90902	847	·92788
740	·86923	776	·88986	812	·90956	848	·92840
741	·86982	777	·89042	813	·91009	849	·92891
742	·87040	778	·89098	814	·91062	850	·92942
743	·87099	779	·89154	815	·91116	851	·92993
744	·87157	780	·89209	816	·91169	852	·93044
745	·87216	781	·89265	817	·91222	853	·93095
746	·87274	782	·89321	818	·91275	854	·93146
747	·87332	783	·89376	819	·91328	855	·93197
748	·87390	784	·89432	820	·91381	856	·93247
749	·87448	785	·89487	821	·91434	857	·93298
750	·87506	786	·89542	822	·91487	858	·93349
751	·87564	787	·89597	823	·91540	859	·93399
752	·87622	788	·89653	824	·91593	860	·93450
753	·87679	789	·89708	825	·91645	861	·93500
754	·87737	790	·89763	826	·91698	862	·93551
755	·87795	791	·89818	827	·91751	863	·93601

Table of Logarithms—*continued.*

Num.	Log.	Num.	Log.	Num.	Log.	Num.	Log.
864	·93651	900	·95424	936	·97128	972	·98767
865	·93702	901	·95472	937	·97174	973	·98811
866	·93752	902	·95521	938	·97220	974	·98856
867	·93802	903	·95569	939	·97267	975	·98900
868	·93852	904	·95617	940	·97313	976	·98945
869	·93902	905	·95665	941	·97359	977	·98989
870	·93952	906	·95713	942	·97405	978	·99034
871	·94002	907	·95761	943	·97451	979	·99078
872	·94052	908	·95809	944	·97497	980	·99123
873	·94101	909	·95856	945	·97543	981	·99167
874	·94151	910	·95904	946	·97589	982	·99211
875	·94201	911	·95952	947	·97635	983	·99255
876	·94250	912	·95999	948	·97681	984	·99300
877	·94300	913	·96047	949	·97727	985	·99344
878	·94349	914	·96095	950	·97772	986	·99388
879	·94399	915	·96142	951	·97818	987	·99432
880	·94448	916	·96190	952	·97864	988	·99476
881	·94498	917	·96237	953	·97909	989	·99520
882	·94547	918	·96284	954	·97955	990	·99564
883	·94596	919	·96332	955	·98000	991	·99607
884	·94645	920	·96379	956	·98046	992	·99651
885	·94694	921	·96426	957	·98091	993	·99695
886	·94743	922	·96473	958	·98137	994	·99739
887	·94792	923	·96520	959	·98182	995	·99782
888	·94841	924	·96567	960	·98227	996	·99826
889	·94890	925	·96614	961	·98272	997	·99870
890	·94939	926	·96661	962	·98318	998	·99913
891	·94988	927	·96708	963	·98363	999	·99957
892	·95036	928	·96755	964	·98408	1000	·00000
893	·95085	929	·96802	965	·98453	—	—
894	·95134	930	·96848	966	·98498	9399	·97307
895	·95182	931	·96895	967	·98543		
896	·95231	932	·96942	968	·98588		
897	·95279	933	·96988	969	·98632		
898	·95328	934	·97035	970	·98677		
899	·95376	935	·97081	971	·98722		

Note *a*, page vii.—The following speculations on the source of electricity in a battery may serve to stimulate reflection, but the student should remember that they are not in accordance with received views.

Since electricity is developed when zinc and other metals combine with oxygen, we may seek for its source either in the metal or in the oxygen; we may, in fact, regard it as a component part of the metal, which is liberated when it combines with oxygen. In this case, since zinc, hydrogen, and the electropositive metals give more electricity, or electricity at a higher tension than the electronegative metals, we are compelled to assume a different combining proportion of electricity for each metal. Let us, on the other hand, suppose the electricity to come from the oxygen; let gaseous oxygen be assumed to consist of two hypothetical substances in combination, viz., *oxyn*, which is oxygen in a simple or elementary condition, and *calon*, which is heat in its latent form. Let heat be simply electricity devoid of tension, all electricity as it falls in tension becoming heat, then—

Gaseous oxygen = oxyn + calon (heat in combination).
Water = oxyn + hydrogen (calon, or heat set free).
Oxide of zinc = oxyn + zinc (calon set free as electricity).
Carbonic acid = oxyn + carbon (calon set free).

The difficulty still arises of explaining how the oxygen as it leaves each negative metal in order to combine with a more positive one (as in the Daniell's battery) produces at every new combination a fresh supply of electricity, or, what is the same question, why it gives a higher tension with some metals than with others.

Azone and oxyn may, perhaps, be identical; hydrogen probably owes its gaseous form to combination with calon, &c. The sun's light acting on carbonic acid in the tissue of plants liberates the carbon, and restores calon to the oxyn, producing gaseous oxygen, and hence our source of power.

Note *b*, page 121. Speed of working.—On the ordinary Morse system of working it is easy to see that the speed must vary as the square of the length, for the cable has to be wholly charged and discharged at each signal, and since with the double length we have twice the quantity of electricity to supply and twice the resistance to supply it through, it takes four times the time. Increase of tension does not in theory alter the speed, for with the double tension the cable holds a double charge, and this counterbalances the increased

velocity: practically it increases the speed to some extent, because the current attains the strength sufficient to work a relay in shorter time with a powerful current than with a weak one, although the speed of both is the same.

To work through the Atlantic cables at their highest speed it is necessary to use a condenser either at one or at both ends of the cable, connected up in the manner described at pp. 130, 131, fig. 41. In this arrangement it is impossible for any electricity to enter or leave the cable. The condensers have a capacity of about twenty farads, and when employed with ten cells they create by induction an impulse of two hundred farads at the near end of the line. For each signal the key is only depressed momentarily, and immediately raised again, so that the electrical impulse only endures for an instant, and the next moment the wave rushes back again to restore the equilibrium; but much of the wave is gone past recall, and continues to roll on to the distant end of the cable, where it strikes against the other condenser, and appears beyond it in the form of an induced wave of 1·4 farads, passing through the galvanometer and deflecting the spot of light about $\frac{5}{8}$ inch momentarily to the right or left and instantly back again to zero. If two or more waves are sent successively in the same direction, the later waves meeting the returning wave are much weakened, and only ·5 farads pass out momentarily through the galvanometer and back again. These waves to the left are equivalent to dots in the Morse alphabet; but when waves are sent first positive and then negative, representing the dot and the dash, each returning wave coincides in direction with its predecessor, and the result is an induced wave through the galvanometer of two farads, and a much larger deflection of the spot of light alternately to the right and left. The smallest quantity of electricity that will work a highly-sensitive polarised relay in its best condition is about 1·5 farads, so that the wave could not be used to work a relay unless the currents were alternately positive and negative.

These waves gradually and rapidly diminish in amplitude as they roll through the cable, and could they be rendered visible would doubtless resemble the undulations seen when a rope lying on the ground is violently agitated up and down at one end. The gradually-diminishing waves roll along it for a considerable distance: the wave is transmitted, but the rope itself remains stationary; just as in the cable no electricity enters or leaves it, but a wave of tension rolls onward within it.

With given amplitudes of wave there is little doubt that the law holds good in this case as in the case of ordinary working, viz., that the speed varies inversely as the square of the distance ; but it is not so clear that the other law holds good, viz., that the speed varies inversely as the inductive capacity. The cable has been worked by the condensers while constantly charged to a tension of one hundred cells positive (see p. 130), and also to the same tension negative, without any visible effect on the speed or the amplitude of the wave. Yet in the one case it contained 67,000 farads more, and in the other 67,000 farads less electricity than its normal quantity stored up inductively on the surface of the conductor. The wave utilises only a fraction of the inductive capacity of the cable, and without further experiment it would be rash to say that the portion of inductive capacity not called into action acts obstructively on the passage of the wave. It would almost appear at first sight that with a given conductor a heavier wave would be capable of being transmitted when the inductive capacity was large than when small—a wave slower in its progress forward, but larger in its volume, and therefore giving a more powerful signal. It is to be regretted that so little facility has been given by the proprietors of existing cables for the determination of these and other similarly interesting questions, seeing that they have so direct and important a bearing on the commercial prospects of telegraphy.

INDEX.

THE END.

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RECE

per.	Dielectri	Approximate Resistance per Knot when laid. Irrespective of temperature and pressure. Resistance of Dielectric.		Resistance of Conductor.
s.	lbs.	* Megohms.		Ohms.
		Malta Tripoli	242	3·59
00	400	Tripoli Benghazi	192	3·56
		Benghazi Alexandria	151	3 54
		Fao-Bushire	495	6·46
		Bushire Mussendom	326	6·21
25	275	Mussendom	[illegible]	[illegible]
107	12		1183	11·83

icity as determi
tive force does
nay be found s
eigh one pound
for any Cable of

LATIMER CLARK.

January, 1868.